PICHER MINING FIELD, NORTHEAST OKLAHOMA
SUBSIDENCE EVALUATION REPORT

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Prepared for:

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Tulsa District

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Subsidence Evaluation Team

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EXECUTIVE SUMMARY

INTRODUCTION

The Picher Mining Field of northeastern Oklahoma was the location of extensive lead and zinc mining from 1904 to 1970. Mine waste accumulations and acid mine water discharge from the now-abandoned lead-zinc mines have become an environmental issue that has been the focus of environmental restoration activities since 1979. The area was designated by the Environmental Protection Agency (EPA) as the Tar Creek Superfund Site in 1983. Extensive underground openings left from the historic mining activity have also resulted in subsidence that presents a serious hazard to public safety, the environment, and current and future land use. The subsidence problem was not systematically addressed as part of the environmental restoration activities. In 2000, Oklahoma Governor Frank Keating established the Tar Creek Task Force to develop a holistic plan for addressing issues identified at the site. Mine subsidence was identified by the Tar Creek Task Force as a major concern, however, no funding was provided to implement recommendations made by the Tar Creek Task Force. In June 2004, Oklahoma Senator Jim Inhofe requested that an evaluation be conducted to assess the potential for future major subsidence in the area. The U.S. Army Corps of Engineers was designated to be the lead agency on the subsidence evaluation project. A technical team was assembled in August 2004 to begin the subsidence evaluation. Composition of the team is presented in Table ES.1, *Subsidence Evaluation Team Organization.*

TABLE ES.1
SUBSIDENCE EVALUATION TEAM ORGANIZATION

Organization	Team Member
Government Organizations	
U.S. Army Corps of Engineers, Tulsa District	Jonna Polk
	James Martell
U. S. Department of the Interior, U.S. Geological Survey	David Fittermen
	Mark Becker
	Bill Ellis
U.S. Department of the Interior, Office of Surface Mining	Len Meier
Oklahoma Conservation Commission	Mike Sharp
Oklahoma Department of Environmental Quality (DEQ)	David Cates
	MaryJane Calvey
Oklahoma Geological Survey	Ken Luza
U.S. Department of the Interior, Bureau of Indian Affairs	Charles Head
Quapaw Tribe	Tim Kent
Contractor Support	
Montgomery, Watson, Harza (MWH)	John Redmond
	Bruce Narloch
	Andrew Rossi
SubTerra, Inc.	Chris Breeds
Keheley & Associates, Inc.	Ed Keheley
Wood Metallurgical Consultants	Frank Wood
Others Contributing to the Evaluation Process	
Oklahoma DEQ	Kelly Dixon
U.S. Department of the Interior, Bureau of Indian Affairs	Bob Coleman
U.S. Army Corps of Engineers, Tulsa District	Adam Crisp
U.S. Department of the Interior, Office of Surface Mining	Paul Behum
MWH	John Pellicer
U.S. Department of the Interior, Bureau of Land Management	Doug Cook
Miami Integris Baptist Hospital	Dr. Mark Osborn

This report describes the evaluation process and the results obtained by the team and presents recommendations for mitigation or avoidance of the subsidence hazards.

The USGS served as an active member of the multi-agency Team by providing scientific and technical expertise to the subsidence evaluation process and by participating in the drafting of certain portions this report. However, consistent with agency policy, the USGS did not participate in the development of any recommendations contained within this report and USGS endorsement of any such recommendations should not be implied.

The subsidence study focused on residential areas and transportation corridors of major significance in the Picher Mining Field. Residential areas identified for evaluation in this study were the communities of Picher Cardin, Hockerville, and Quapaw. Mining records show that neither Commerce nor North Miami is significantly undermined. Mine maps for mines beneath the City of Quapaw were not located, and the only known information for the mines in the Quapaw area is the location of several mineshafts. Transportation corridors considered for evaluation in this study were Highway 69 from the junction of Highway 69 and 69A north through Picher to the Kansas state line, Highway 69A through Quapaw to the Kansas state line, East 20 Road (A Street) from the west side of Picher to the junction with Highway 69A, and Cardin Road from the junction with Highway 69 in Picher to the junction north of Commerce. These residential areas and transportation corridors are referred to collectively as the study area.

Public safety implications of subsidence have concerned the residents in the study area for many years. Shaft related and non-shaft related subsidence events have occurred in the Picher Mining Field since the beginning of mining operations and continue to occur. Unfortunately, records of the locations of past subsidence events are incomplete, and many events that occurred prior to 1960 were not recorded in a formal manner, which would allow for easy identification and analysis.

Several environmental issues are associated with subsidence in the study area: surface runoff into subsidence sites, modification to drainage systems, water quality degradation and the unauthorized dumping of commercial and residential trash in the subsidence sites. Surface water runoff problems have dated back to the beginning of mining in the Picher Mining Field. As the mines were abandoned and subsidence events occurred, surface runoff began to fill the mines and the larger subsidence features. A recent field evaluation of mine shafts and subsidence features identified an extensive amount of commercial and residential waste in open mine shafts, and shaft related and non-shaft related subsidence features. Examples of waste found include animal carcasses, chemicals, human waste, tires, construction materials, and motor oil.

Residents and city, state, federal, and elected officials have discussed the safe and economical use of the undermined lands in northeastern Ottawa County for many years. The vast extent of the underground mine workings, the potential for future subsidence, and the large amount of surface area covered by mill tailings have hampered the ability to reasonably explore viable future land use options for the study area.

To address the above concerns, the Subsidence Evaluation Team identified two primary products that would be necessary to estimate the location, extent and magnitude of future mine subsidence in the study area. These products are:

- Exhibits that depict the location of mine workings, shaft locations, non-shaft related collapses, roof falls, and the estimated maximum subsidence from mine workings combined into one map per section.
- Figures that present the results of the analytical tool used to determine the probability of subsidence based on pre-1973 major subsidence at or adjacent to major transportation corridors, residences and structures. This is recommended as a tool to prioritize areas for further evaluation and mitigation.

Estimated Maximum Subsidence

Site-wide information on geology, mine map availability, and drill-hole logs were reviewed. The Evaluation Team had mine maps from multiple sources and drill-hole logs from Missouri Southern State University scanned. High-resolution aerial photography and other supporting data were obtained from numerous sources.

Exhibits were prepared to show the estimated maximum subsidence from the mine workings in the study area. Estimated maximum subsidence was defined for this study as the maximum amount of subsidence (measured in feet) that could occur at a given surface location as a result of the collapse of mine workings. This value is calculated based on the height of the mine workings and bulking factors for the geologic units over the mine workings. In other words, if the material over mine workings were to collapse, the maximum amount of subsidence that could propagate to the surface is equal to the height from the floor of the mine working to the surface minus the height of the overlying material, multiplied by a bulking factor. The maximum estimated subsidence values were grouped into six categories and ranged from less than 2 feet to greater than 50 feet.

A total of 286 numbered locations in the study area were predicted to have some degree of subsidence if the mine workings were to collapse. A 150-ft buffer zone was drawn around the sites to account for mine-map-location inaccuracies and an angle of draw. The summary of subsidence locations (numbered sites) within the study area includes:

- 54 locations under or within approximately 150 feet of residences or structures
- 33 locations under or within approximately 150 feet of major transportation corridors
- 13 locations under or within approximately 150 feet of both residences or structures and major transportation corridors
- 3 locations under or within approximately 150 feet of public use areas (parks, playgrounds)
- 183 locations under or within approximately 150 feet of other areas or structures not listed above (city streets, rural roads, pasture lands, chat piles, wooded lands, wetlands, and other undeveloped land)

Undermined rural locations outside of Picher, Cardin, and Hockerville with potential subsidence are divided into the following categories:

- 7 locations under or within 150 feet of Residences or Structures
- 29 locations under or within 150 feet of major transportation corridors
- 17 locations under or within 150 feet of rural roads
- 0 locations under or within 150 feet of public parks and playgrounds
- 3 locations under or within 150 feet of railroads

The summary of the residential structures, parks and playgrounds, community streets and major transportation corridors that are above and/or within 150 feet of the locations of estimated maximum subsidence in the three communities in the study area includes:

Picher

- 139 Residential Structures
- 11 Business Structures
- 13 Public Use Structures/Facilities:
  - 6 Churches
  - 1 City Maintenance Facility
  - 1 Lodge Facility
  - 1 Picher Mining Field Museum
  - 4 Parks/Playgrounds
- 53 streets are above and/or within 150 feet of a potential subsidence location
- 25 locations under and/or within 150 feet of a major transportation corridor within the city limits

A total of 159 residential, business and public use structures in Picher have the potential of some degree of subsidence. This number does not include the 4 public use parks/playgrounds. Eleven of the residences and one business appear to be abandoned.

Cardin

- 33 Residential Structures
- 6 Business Structures
- 3 Public Use Structures/Facilities
  - 3 Churches
  - 0 Public Parks and Playgrounds
- 14 streets under and/or within 150 feet of a potential subsidence location
- 4 locations under and/or within 150 feet of a major transportation corridor

A total of 42 residential, business and public use structures have the potential of some degree of subsidence. Three residences and four businesses appear to be abandoned.

Hockerville

Undermined areas within Hockerville are defined for purposes of this report as the area between 20 Road to the south and State Line Road to the north, and 604 Road to the west and 610 Road to the east.

- 4 Residential Structures
- 1 Business Structure
- 1 Public Use Structure/Facility:
  - 1 Church
  - 0 Public Parks and Playgrounds
- 7 locations under and/or within 150 feet of Community Streets
- 1 location under and/or within 150 feet of a Major Transportation Corridor

Probability Analysis

Mechanisms leading to subsidence, based on previous experience in analyzing and predicting subsidence potential, were reviewed to determine if subsidence prediction methods were available for application in the study area. Due to the unique mining methods used in the Picher Mining Field, none of the subsidence prediction methods reviewed was directly applicable to the study, but rather served as relevant background for development of the subsidence evaluation.

Information available for the Picher Mining Field related to mine subsidence is generally limited to mine mapping and geologic information. The lack of detailed rock mechanics data for the study area and the need to use available information in any forward analysis limited the analytical approach for this subsidence evaluation. Therefore, several large non-shaft subsidence areas and non-subsidence areas were back-analyzed to identify factors that control non-shaft related subsidence in the study area.

The purpose of the back-analysis of large, existing subsidence features resulting from mine collapse was to identify those factors or combinations of factors that are common to those features. Variables associated with past surface collapse and non-collapse case studies were tabulated and analyzed statistically to determine the factors and/or combinations of factors that appeared to be most associated with large surface collapses. These critical factors were then used to evaluate the probability of future subsidence in the target areas based on a representative sampling of major subsidence documented to have occurred prior to 1973. Target areas where such factors are present, and are considered to have a higher probability, can be prioritized for future assessment and mitigation.

One of the major limitations to this approach is that all but one of the subsidence cases selected for back-analysis were major surface collapses, with horizontal dimensions on the order of 100 feet or greater and subsidence of several tens of feet. These larger features were selected because they represent the greatest potential threat to public safety and almost certainly result from the collapse of large underground rooms, or stopes. Smaller subsidence features, which do occur in the Picher Mining Field, are less easily identified and can result from processes other than mine collapse, such as shaft cribbing failure and dissolution of limestone resulting in karstic features. Trough subsidence, characterized by shallow subsidence over relatively large areas, was also not included in this analysis. Trough subsidence, while possibly present in the Picher Mining Field, is not easily identified and has not been well defined in the region. The screening criteria that result from this back-analysis are therefore only applicable in identifying potential areas of large surface collapse similar in nature to the back-analysis case studies considered.

The probability of subsidence, based on a representative sampling of major subsidence that occurred prior to 1973, was evaluated for 133 areas where subsidence could occur within 150 feet of residences, other structures or major transportation corridors. The evaluation provides a numerical prediction of the probability of future subsidence at these locations based on the similarity in characteristics with those of the collapsed mine workings of the back-analysis case studies. This method cannot predict when subsidence will occur. The probability analysis is useful as a tool to prioritize locations to be addressed.

From the data assembled and evaluations completed as part of this study, the following is a summary of the major findings:

- 3,130 acres in the 4,400-acre study area were not undermined. However, 1,270 acres were undermined, of which 88 acres displayed greater than nominal potential for subsidence. The 88 acres found to display greater than nominal potential for subsidence were identified as 286 separate locations and/or clusters.
- Subsidence can occur with little or no advance warning.
- Methodologies are not currently available to accurately predict when subsidence will occur.
- 473 acres of the 1,390 acres of the town of Picher that are located within the study area are undermined.
- 17 acres of the 58 acres of the town of Cardin that are located within the study area are undermined.
- 25 acres of the 231 acres of the town of Hockerville that are located within the study area are undermined.
- The Subsidence Evaluation Team located no maps of mines in the vicinity of the town of Quapaw, and as a result, the extent of the undermining of Quapaw is unknown. The presence of mine shafts and mill sites in the area, however, indicates that significant mining may have occurred beneath the town.
- 4.5 miles of the 19 miles of major transportation corridors in the study area are undermined.
- 15 shaft related and 20 non-shaft related subsidences have occurred in the study area since the 1982 inventory by OGS.
- Factors identified as contributing most to non-shaft related subsidence are width of stope, height of stope, combined thickness of the Boone Formation and Chester above the stope, and depth of stope.
- Current groundwater levels in the study area provide a buoyant effect that reduces the effective load on remnant pillars and mine roofs and therefore may decrease the potential for subsidence.

- Mine maps are of different vintages and the most recent maps do not always include mine workings shown on older maps. Also, discrepancies exist between mine maps within the same lease.
- Map symbols used to indicate different mine levels can be inconsistent from lease to lease, and in some cases are inconsistent within the same lease.
- Interpretation of mine maps is sometimes difficult in areas of multiple-level mining because of overlapping and/or inconsistent map symbols.
- The mine floor and roof elevations can be estimated by using assay data from exploration borehole logs.
- The geology is variable within short distances, as indicated by the exploration borehole logs and available published reports.
- The extraction ratio for many of the mines, calculated from the detailed mine maps, is greater than 90%.
- There is very little existing geotechnical or rock mechanical data to assess the probability of subsidence using available analytical methods.
- There is very little documentation available regarding the shaving and removal of pillars, except for a few isolated cases.
- Details of the mechanics of non-shaft related subsidence in the study area are poorly understood.
- Post-mining subsidence features (post-1970) in the Picher Mining Field have tended to be smaller in size than previous collapses, perhaps indicating a differing collapse and subsidence mechanism than in the earlier collapses.
- Some existing houses in the Picher area most likely do not meet HUD requirements for habitability or for financing home improvements or sales.
- Some areas in the mining field are not suitable for residential or business development given the safety risks and the cost to mitigate them.

Conclusions

The major conclusions of this study include:

- The potential for shaft related and non-shaft related subsidence is a very serious threat to the safety and economic well-being of people who reside in and travel through the area.
- The area exposed to subsidence hazards is a relatively small percentage of the total study area, but some residential and public-use areas and portions of transportation corridors are subject to some degree of subsidence hazard.
- 4,312 acres (not including buffer zones) of the 4,400-acre study area are not subject to subsidence based on limited evaluation of available information from mine maps and conservative estimates of rock bulking factors. Further review of all available information may reveal additional areas subject to potential subsidence.
- Based on the back-analysis of failed mine workings, it is probable that additional non-shaft related failures will occur in the future.
- Every shaft has the potential to collapse, and the initial opening of a shaft collapse is likely to be the dimension of the shaft, and may grow as large as 30 feet in diameter.

- The quantifiable variables of 1) width of stope, 2) height of stope, 3) combined thickness of Boone Formation and Chester above the stope, and 4) depth of stope can be effectively used to estimate the probability of subsidence.
- A preliminary predictive tool has been developed that enables prediction of the probability of future subsidence potential in the Picher Mining Field.
- The magnitudes of possible subsidence at locations evaluated in this study range from less than 1 foot to greater than 50 feet, with the attendant possibility of loss of life and/or property, depending upon where the subsidence occurs.
- Land use determines the potential impact of a subsidence event on the population. For example, a one-foot subsidence in a road has more serious consequences than a similar or even larger subsidence in an agricultural area.
- Lowering of the groundwater table to levels below mine roof elevations may locally increase the probability of subsidence. This would probably only occur through pumping. However, water level fluctuations may cause increased shaft related collapses.
- A thorough evaluation of subsidence potential of a mined area must include a careful review of all available mine maps.
- It is likely that subsidence features exist in the study area and were not identified.
- No funding mechanism exists for emergency response to subsidence.

General Recommendations

Based on the results, findings and conclusions of the study, recommendations were developed for the study area. The recommendations are divided into two major categories. The first contains a list of general recommendations that constitute the minimum safety approaches that should be implemented. The second contains a list of site specific recommendations that require a more comprehensive management evaluation to implement. Due to the anticipated high cost of some of the recommendations, the Subsidence Evaluation Team recommends using a cost-benefit analysis as the primary management tool for decision making. A cost-benefit analysis of all available options should be performed to provide the basis for determining the most appropriate final decision.

The following constitute a summary listing of the Subsidence Evaluation Team's general recommendations:

- Establish an advisory committee composed of federal, state, and local representatives to assist with the implementation of recommendations contained in this report and to serve as a technical and/or management resource for policy makers and elected officials.
- Establish a long-term program to locate, map, and record future subsidence events as they occur in the Picher Mining Field. Both shaft related and non-shaft related subsidence events should be included in the program.
- Establish a fund to address emergency subsidence events in the Picher Mining Field. The fund should provide for emergency evaluation of subsidence features as they occur and provide an immediate funding source for corrective measures. Existing funding mechanisms do not provide the ability to respond quickly to emergencies. The fund would be replenished as it is drawn down.
- Continue the current mine-shaft closure program to remove the immediate hazards associated with open shafts, further reduce the potential for additional shaft failures, and minimize the environmental impacts from surface water drainage and unauthorized dumping. Focus mine-shaft closure efforts first on open mine shafts within city limits and near occupied structures.
- Develop and implement a subsidence training program for workers from Picher, Quapaw, Commerce, Ottawa County District 1, and Oklahoma Department of Transportation (ODOT) maintenance staff. The program should be designed to teach workers to recognize and report subsidence events and how to take

appropriate action to address the subsidence events as they occur. A similar program was developed in Joplin, MO, and has worked effectively for several years.

- Identify and inspect all shaft related and non-shaft related subsidence features being used as dump sites for commercial and household refuse to reduce the environmental impacts of open subsidence features. A priority ranking based on the potential environmental impact should be developed and additional funding provided to eliminate surface runoff into the sites and, in some instances, close the sites not currently addressed. Governmental regulatory agencies, cities, and Ottawa County should work together to strengthen the regulations, enforcement, and penalties for unauthorized dumping and develop legal alternatives for trash disposal.
- Federal and State agencies involved in remediation and reclamation of lands at Tar Creek should reevaluate existing assumptions and approaches used to address hazards in the mining field. The information contained in this report (potential subsidence and mine shaft failure, underground mine workings) should be factored into existing projects, plans, and decisions. A process for evaluating current and future land use plans against existing hazards and the estimated cost for remediation and reclamation should be developed. A plan for restoration and/or final disposition of mined properties, including identification and mitigation of known hazards, should be a product of the effort. Ottawa County and impacted cities should establish a county-city land use planning process to evaluate current land use and develop future land use recommendations in the study area. Ottawa County should adopt building standards and land use guidelines for the mined lands.
- HUD regulations related to existing housing and future construction in the mining field should be reviewed to determine the applicability and impact.
- Identify a state agency responsible for maintaining and building upon the GIS developed from this project. The GIS information should be made available over the Internet or by some other electronic media.
- Complete subsidence evaluation for the remainder of the Picher Mining Field outside the study area and:
  - Further refine the subsidence evaluation model
  - Evaluate the effects of mine water on the stability of mine workings
  - Develop a better understanding of structural geology and physical and engineering properties of rock in the area
  - Incorporate additional mine maps and borehole data in the GIS
  - Evaluate failure mechanisms for recent smaller, non-shaft subsidence areas

SITE-SPECIFIC RECOMMENDATIONS

Given the study's conclusions, measures are required to mitigate the potential adverse impacts to public safety. Prior to implementing the following recommendations, a cost-benefit analysis should be performed to determine the most appropriate approach. Areas with higher probabilities of subsidence and greater consequence should be given priority with regard to evaluation and mitigation. The following constitute a summary listing of the Subsidence Evaluation Team's site-specific recommendations for public use areas, residential/commercial areas, major transportation corridors, residential streets and rural, agricultural and undeveloped areas:

For Public Use Facilities—Areas Where People Congregate Having a Maximum Estimated Subsidence of Five Feet or Greater:

- Three options are available: close/relocate the facility, conduct a site-specific evaluation followed by either a geotechnical evaluation, or perform regular monitoring using visual or geotechnical methods. The costs of the evaluation, and possible long-term monitoring should be determined. The benefits of continuing to use these facilities should be evaluated against the risk and overall costs of closure/relocation, the geotechnical evaluation, and long term-monitoring.

- Locations in Picher where residents were previously evicted by the Eagle-Picher Mining & Smelting Company and public use was restricted by Eagle-Picher and BIA because of the potential for subsidence should be further evaluated prior to development of public use facilities or expansion of residential areas. The grade school playground (location 139), the youth soccer field (location 141), Reunion Park (location 140), Picher Little League Park (old baseball field in Picher on South Main between 5th and 6th Streets), between 1st and A Streets and north of D Street between Netta and Picher Streets, and other areas of high public use should be evaluated to determine if continued use is safe for residents.

Residential/Commercial Areas:

- Mineshafts in Residential, Commercial or Public Use Areas: City and county workers should be trained to recognize the signs of potential mineshaft failure and periodically inspect all mineshafts located in the community. These areas should be zoned to restrict future residential, commercial, or public land use. The mine shafts should be investigated to determine if they are filled with durable material. If it is not, the shaft should be backfilled or plugged with concrete at the rock interface.
- Mineshafts Beneath Structures: If a structure is located immediately over a shaft, the structure should be relocated or demolished, or if cost effective, an angle drilling program should be conducted to determine if the shaft is completely backfilled. If drilling determines that the shaft is not completely backfilled or otherwise adequately plugged, the shaft should be backfilled or the structure should be relocated or demolished. After relocation or demolition of the structure, the shaft should be plugged at the rock interface or backfilled with non-degradable material. The cost of backfilling a shaft under a structure using angle drilling and grouting methods can be substantially greater than backfilling or plugging the same shaft without the structure. This entails drilling to determine the presence of mine voids and their depth and height, along with rock mechanics properties of the formation.
- Estimated Maximum Subsidence Five Feet or Greater: When a structure or structures overlies, or is within 150 feet of such an area, one of three options should be undertaken: perform exploratory drilling to determine the actual subsurface conditions, relocate the structure or structures, or demolish the structure or structures. Exploratory drilling may validate the original prediction, may show that the maximum estimated subsidence is either greater or less, and/or may reveal different information about the site such as the progression of mine roof collapse upward. If drilling shows that the site is not safe for continued occupation or use and mitigation is not a feasible option, then relocation or demolition should be conducted. Any demolition must be followed by restrictions on future land uses. It is recommended that no new construction or relocation of residential housing, commercial buildings, infrastructure, or transportation systems be allowed immediately above or within 150 feet of undermined lands until the area is evaluated for potential subsidence.
- Residential Areas of Quapaw: Based on the small number of mine shafts identified in Quapaw, the mine workings are most likely not extensive or located near the surface. Competent limestone is found near the surface in other mines near Quapaw indicating a competent mine roof structure. The cost to perform a geotechnical evaluation to identify the extent of the mine workings, the height of the workings and the stability of the roof structure would be very expensive and disruptive to the community. Based on the absence of non-shaft related subsidence in the past, city workers should be trained to recognize and report any indications of subsidence or shaft failure.

Major Transportation Corridors:

Even small collapses on transportation corridors have the potential to cause serious accidents. For all transportation corridors that have an estimated maximum subsidence of 0 to 2 feet, under or within 150 feet of the road, establish and implement a routine survey grade monitoring procedure, the results of which are reviewed by a qualified engineer on a prescribed schedule.

For all transportation corridors that have an estimated maximum subsidence of 2 feet or greater, under or within 150 feet of the road, or where a mine shaft is located under the road right of way, immediate recommendations are:

- Inform transportation and utility managers of potential risk
- Consider imposing weight restrictions and speed limits on vehicles
- Establish alternate routes for school buses

Long-term recommendations are:

- Establish a systematic, continuous monitoring and reporting program including at a minimum, survey grade network along effected areas.
- Ensure that a qualified engineer or geologist reviews the monitoring data at regular intervals as a check on the quality control for the monitoring system.
- Conduct a geotechnical investigation to determine the stability of the road bed, surface and right-of-way.
- Train city, county and state transportation workers to recognize the signs of subsidence of shaft failure and provide a mechanism to expedite response to any suspected problem.
- Establish a standard protocol for all city, county and state officials to use whenever they suspect that a shaft failure or subsidence may be occurring in or adjacent to a road. This should include notification procedures, road closure procedures warning sign procedures, etc.
- Consider mitigation if cost effective

Residential Streets:

Several residential streets in Picher, Cardin, and Hockerville have the potential for subsidence beneath or adjacent to the streets. Several streets in these towns have been built over mine workings; however, not all streets built over mine workings were identified as having a potential for subsidence. Federal, state, and local officials should assess the need for evaluating the streets having a potential for subsidence and other streets that overlie mine workings. For all residential streets that have an estimated maximum subsidence of 0 to 2 feet, under or within 150 feet of the road, establish and implement a routine survey grade monitoring procedure, the results of which are reviewed by a qualified engineer on a prescribed schedule.

For residential streets that have an estimated maximum subsidence greater than 2 feet, immediate recommendations are:

- Consider imposing weight restrictions and speed limits on vehicles
- Establish alternate routes for school buses

Long-term recommendations are:

- Establish a systematic, continuous monitoring and reporting program including at a minimum, survey grade network along effected areas.
- Ensure that a qualified engineer or geologist reviews the monitoring data at regular intervals as a check on the quality control for the monitoring system.
- Conduct a geotechnical investigation to determine the stability of the road bed, surface and right-of-way.
- Train city, county and state transportation workers to recognize the signs of subsidence of shaft failure and provide a mechanism to expedite response to any suspected problem.

- Establish a standard protocol for all city, county and state officials to use whenever they suspect that a shaft failure or subsidence may be occurring in or adjacent to a road. This should include notification procedures, road closure procedures warning sign procedures, etc.
- Consider mitigation if cost effective

Rural, Agricultural and Undeveloped Areas

Areas used for pasture, hay, or row crops, and undeveloped areas used for hunting, off-road vehicle use, or hiking expose fewer people to dangers associated with subsidence than do roads or residential areas; yet, dangers to public safety and property still exist. Undeveloped and lightly developed portions of towns are likely locations for new construction or relocation of existing structures from other areas. It is recommended that no new construction or relocation of residential housing, commercial buildings, infrastructure, or transportation systems be allowed immediately above or within 150 feet of undermined lands until the area is evaluated for potential subsidence.

Options

In addition to the recommendations, the report also presents options to address some of the existing subsidence features. The options are divided into four categories including:

- Management approaches that may be used to address subsidence.
- Instrumentation that could be installed for early detection of potential surface collapse.
- Mine geometry characterization to better understand the parameters contributing to potential surface collapse.
- Hazard mitigation options (hazard abatement) associated with subsidence

1 Introduction

Photograph taken in the 1.5-acre mine subsidence that occurred on the northwest side of Picher in 1967. Four homes containing 18 residents were involved in the subsidence event.

1. INTRODUCTION

The Picher Mining Field of northeastern Oklahoma was the location of extensive lead and zinc mining from 1904 to 1970. Mine waste accumulations and acid mine-water discharge from the now-abandoned lead and zinc mines have been the focus of environmental restoration activities since 1979. The area was designated by the Environmental Protection Agency (EPA) as the Tar Creek Superfund Site in 1983. Extensive underground openings left from the historic mining activity have also resulted in subsidence that presents a serious hazard to public safety, the environment, and current and future land use. The subsidence problem has not been systematically addressed as part of the environmental restoration activities. In 2000, Oklahoma Governor Frank Keating established the Tar Creek Superfund Task Force to develop a holistic plan for addressing issues identified at the site. Mine subsidence was identified by the Tar Creek task force as a major concern; however, no funding was provided to implement recommendations of the task force. In June 2004, Oklahoma Senator Jim Inhofe requested that an evaluation be conducted to assess the potential for future major subsidence in the area. The U.S. Army Corps of Engineers (U.S. Army Corps) was designated to be the lead agency on the project. A Subsidence Evaluation Team was assembled in August 2004 to begin the subsidence evaluation. The evaluation focused on the populated areas and transportation corridors in and around Picher, Cardin, Hockerville, and Quapaw, Oklahoma. This report describes the evaluation process developed by the Subsidence Evaluation Team, and presents the results obtained and recommendations for mitigation of the subsidence hazards.

1.1 IMPACTS OF SUBSIDENCE

1.1.1 Public Safety

The safety implications of subsidence have been a concern of residents in the study area for many years. Shaft-related and non-shaft related subsidence events have occurred in the Picher Mining Field since the beginning of mining operations and continue to occur. Unfortunately, records of the locations of past subsidence events are incomplete, and many events that occurred prior to 1960 were not recorded in a formal manner for easy identification and analysis. In addition, as former miners pass away over time, personal accounts of earlier subsidence are being lost. Luza (1986) provides the most complete account of subsidence events prior to 1983. Additional accounts of subsidence may also be found in news articles of the period.

Residents of the study area are also concerned with the threat of future subsidence as the mine workings further deteriorate. Recent fieldwork shows that subsidence has continued to occur in the mining field since the Luza (1986) study was completed. Section 4 and Tables 4.1 and 4.2 summarize shaft related and non-shaft related subsidence events that were recorded from 1982 to 2005 (Keheley, 2005: personal communication). In addition, some of the existing collapse features have enlarged while others previously filled have re-collapsed or are showing signs of continued major failure. The last 20 years of observation have shown that collapse features, improperly filled with decomposable material and/or mill tailings in the form of chat and flotation fines, have the potential of re-collapse when the fill material migrates downward into the mine workings.

Below is a brief itemization of events where subsidence had a substantial or potential impact on the safety of residents in the study area:

- In the mid 1960s, a young girl fell approximately 30 feet into an open mine shaft, landing on a pile of debris floating on the water in the shaft. The debris cushioned her fall and her injuries were minimal.
- On July 21, 1967, a 1.5-acre collapse involving 4 homes and 18 residents occurred in the Netta White mine in northwest Picher. The ground surface near the center of the collapse dropped 25 feet. While considerable property damage occurred, there were no serious injuries.
- In the 1960s and 1970s, recreational riders of motorcycles and dune buggies from the four-state area regularly came to the Picher-Cardin area to ride on the chat piles. Camping sites were developed to accommodate the riders. Many injuries occurred due to excessive speed and lack of familiarity with the area.

In several instances, major accidents occurred, including broken limbs and complete paralysis, when riders inadvertently drove into subsidence features on or adjacent to the chat piles (Osborn, 2005: personal conversation).

- In 1968, a mine shaft on the Black Hawk lease collapsed between two homes in the federal housing complex in Picher. Many children were living in the complex at the time. The shaft was filled and fenced before any injuries occurred.
- In 1974, a mine shaft collapsed beneath the Leatherman home on Alta Street in Picher. One room of the house fell into the shaft opening. Fortunately, there were no injuries.
- On May 31, 1978, a large collapse occurred on A Street 2.5 miles east of Picher. The collapse eventually reached a size of 90 feet long, 40 feet wide, and 50 feet deep. Before the collapse could be filled, a motorist was killed when he drove into a chat berm placed across the road to prevent drivers from inadvertently driving into the collapse.

1.1.2 Local Environment

There are several environmental issues associated with subsidence in the study area. These issues include surface runoff into subsidence sites, modification of surface drainage systems, surface water quality degradation, and the unauthorized dumping of commercial and residential trash at the subsidence sites. Mining has affected surface runoff since the beginning of mining at the Picher Mining Field. Due to the relatively flat topography at the site, heavy rains often plagued the mining companies by creating large amounts of surface runoff that found its way to open mine shafts and flooded the mine workings (McCuskey, 1935). As the mines were abandoned and subsidence events occurred, surface runoff began to fill the mines and the larger subsidence features.

Natural surface drainage patterns throughout the mining field have been significantly altered by mill tailings and other contributing factors to the point where large and small subsidence features now act as retention reservoirs for surface runoff at many locations. Open mine shafts and large subsidence features collect a significant amount of the total surface runoff from the area. Most of the retained water in the subsidence features slowly drains into the abandoned mine workings.

Ken Luza, of the Oklahoma Geological Survey (OGS), and Ed Keheley, of Keheley Associates, conducted a 15-month field evaluation of mine shafts and subsidence features at the 43-square-mile Picher Mining Field in 2004-2005. One notable aspect of the evaluation was the extensive amount of commercial and residential waste found in open mine shafts and subsidence features. Examples of waste found include animal carcasses, chemicals, human waste, non-municipal sewage discharges, tires, construction materials, and motor oil. It was noted in the evaluation that many of the open mine shafts on private land are being used as waste dumps. In addition, the evaluation found that most of the open mine shafts are partially filled with water. The overall effect on water quality from such waste disposal in the mining field has not been evaluated.

1.1.3 Land Use Options

The safe and economical use of the undermined lands in northeastern Ottawa County has been discussed by residents and city, state, federal, and elected officials for many years. The vast extent of the underground mine workings, the potential for future subsidence, and the large amount of surface area covered by mill tailings has hampered the ability to reasonably explore viable future land use options for the study area.

The threat of subsidence in Picher has been a concern of residents for many years. Beginning in 1950, several subsidence events occurred, after which restrictions were placed on public use of land areas in Picher. The Eagle-Picher Mining and Smelting Company and the U. S. Bureau of Indian Affairs (BIA) took action on several residential and public use properties in Picher to remove residents and deny public use of the areas due to severe undermining. A brief listing of the actions taken by Eagle-Picher and the BIA is provided below.

- Netta East Mine–In February 1950 the Eagle-Picher Company issued written notices to tenants to vacate five city blocks (8.45 acres) in the heart of the business district in Picher within 30 days due to severe undermining (Miami News Record, Feb. 7, 1950). The land was owned by Eagle-Picher at the time.

Eagle-Picher officials formally notified Picher city officials and tenants in the area that, "You should vacate the area immediately for your own safety." Subsequently the area was vacated and fenced until 1997.

- Netta East Mine–North of Picher Reunion Park bounded by A Street on the north, 1st Street on the south, Connell Ave on the east and the lease boundary on the west is identified on Eagle-Picher mine maps as "restricted" (8.74 acres). The area was not made available by Eagle-Picher to relocate the adjoining business district it vacated in February 1950, and the area has never been developed.
- Block 14, Comba Addition–The BIA revoked the City of Picher Property Lease for Block 14 following an inspection of the mine workings beneath the area in April 1968. The area included the former Picher Little League Ball Park on the east side of South Main Street in Block 14 on the northwest side of the northern most Premier chat pile on the Premier mine lease. Block 14 is located between East 5th and 6th Streets between South Main Street and Connell Avenue.
- Netta West Mine- In May 1968, Eagle-Picher issued residents a written 30-day notice to vacate the two blocks east of the grade school. The area is bounded by A Street on the north, West 2nd Street on the south, Vantage Street on the west, and Frisco Street on the east. In 2004, a playground for the grade school was built on the property.
- Section 17, Picher–In the same time frame as described above, Eagle-Picher issued residents a 30-day notice to vacate a two-block area in Picher on the Big Chief mine lease north of the area cited above. The area is bounded by F Street on the North, D Street on the south, Netta Street on the west, and Picher Street on the east.

Beginning in 1967 agencies of the federal government involved with mining in the Picher Mining Field began to focus on the long-term impacts of mining in Ottawa County, Oklahoma and Cherokee County, Kansas. Specifically, the potential impacts of subsidence on long-term land use were of concern to the U. S. Bureau of Mines (Stroup and Stroud, 1967). Stroup and Stroud (1967) indicated a need to provide solutions for the closure of mine openings (shafts and areas caved from surface to depths) and the stabilization of areas subject to subsidence caused by underground workings.

In 1967, the U.S. Bureau of Mines and U.S. Geological Survey initiated an investigation of subsidence and the safety of underground employees in the Picher Mining Field (Westfield and Blessing, 1967). The investigation consisted of observing subsidence, the condition of highways and communities located over mining areas, trips underground, and conferences with mine operators, mine inspectors, and elected officials. Recommendations provided in the final report addressed improved processes for pillar trimming and removal, limiting mining operations to reduce hazards, conducting engineering evaluations of specified areas, and providing physical protection of some existing caved areas.

There were no local, county or state planning activities in place in 1967 that had an impact on mining industry operations (Stroup and Stroud, 1967). There are no local building codes and zoning ordinances related to past mining activities in place in 2005 for northeastern Ottawa County.

The impacts of complying with the U.S. Department of Housing and Urban Development (HUD) regulations for existing housing and future purchases of properties in the Picher Mining Field with respect to residents' health and safety, and obtaining loans have not been evaluated. HUD regulations establish a broad range of requirements for existing housing for one to four family units (Directive No. 4905.1 Rev. 1, 1994) and minimal property standards for housing (Directive No. 4910.1). Both directives address hazards criteria applicable to HUD housing and properties. Chapter 2 of the Directive 4905.1 contains the minimum acceptable hazards criteria. The Directive states, "The property must be free of hazards which may adversely affect the health and safety of the occupants or the structural soundness of the improvements, or which may impair the customary use and enjoyment of the property by the occupants. The hazards may be subsidence, flood, erosion, defective lead-based paint (24 CFR Part 35) or the like."

The HUD Builders Certification form (HUD-92541-4/2001) requires the builder of HUD-approved homes to certify if the site is on an EPA National Priorities List (NPL) or equivalent. If so, a copy of a state-licensed engineer's (soils and structural) reports, designs, and/or certifications showing compliance with HUD requirements to ensure the structural soundness of the improvements and the health and safety of the occupants are to be provided. The applicability of HUD certifications for building in a Superfund site and the associated impacts has not been fully assessed. There are specific cases of lending institutions refusing to lend money to purchase properties inside the Tar Creek Superfund Site.

1.2 CURRENT PROGRAMS

The U.S. Army Corps is implementing a plan under two funding sources to plug and cap the open and collapsing mine shafts identified in the Picher Mining Field. Funding has been appropriated through the U.S. Army Corps of Engineers Restoration of Abandoned Mine Sites (RAMS) program and Section 111 of the Energy and Water Development Appropriations Act, 2004. The Oklahoma Department of Environmental Quality (ODEQ) and the Oklahoma Conservation Commission (OCC) are planning additional shaft plugging under different authorities and funding. All mine shafts are being plugged and capped primarily for public safety reasons, to prevent water infiltration and erosion leading to additional collapse, and to prevent further use as illegal refuse disposal sites. Shaft closing has been an ongoing process during and after mining. Private individuals have performed most shaft closure since 1970. The OCC is filling subsidence areas (large collapses) as part of the land reclamation projects.

1.3 SCOPE

1.3.1 Problem Definition

Mines in the Picher Mining Field are at depths ranging from 60 to 350 feet below the ground surface and present the potential to collapse and affect population and infrastructure. Multiple-level mining, with some void heights reaching 125 feet or more, in populated areas increases the potential for collapse. Since 1967, some effort has been expended to better understand the mechanics of subsidence for the Picher Mining Field. However, no comprehensive work has been initiated to assess the current stability of the mine workings or to determine the potential for future subsidence. Furthermore, a comprehensive evaluation of the impacts of past and future subsidence events on public safety, the environment, and current and future land use has never been undertaken.

1.3.2 Study Area Definition

The U.S. Army Corps gave the Subsidence Evaluation Team a time frame of one year to conduct this initial assessment. Due to this time frame and the amount of data assimilation and processing required for such a large area, it was impractical to assess the entire mining field for the potential of future subsidence. Therefore, it was decided that an assessment of residential areas and major transportation corridors would be the first. Other areas where significant past mining practices and/or geological considerations indicate possible subsidence potential were listed as areas of secondary concern for future evaluation (e.g., railroads, power lines, natural gas transmission lines, rural areas, nonresidential areas).

The residential areas considered in this study were the communities of Picher–Cardin, Hockerville, and Quapaw. Mining records show that neither Commerce nor North Miami was significantly undermined. Mine maps for the City of Quapaw area have not been located. The only available information related to mining in the Quapaw area is the surface location of several mine shafts.

Transportation corridors considered in this study were Highway 69 from the junction of Highways 69 and 69A north through Picher to the Kansas state line, Highway 69A through Quapaw to the Kansas state line, East 20 Road (A Street) from the west side of Picher to the junction with Highway 69A, and the Cardin Road from the junction with Highway 69 in Picher to the junction north of Commerce (see Figure 1.1). All areas within 150 feet of the transportation corridors listed above were considered in this study.

Only a broad-based assessment of the mine workings and mine working levels based on the latest known mine maps and geologic and drill hole information was achievable for the study area. Further detailed analysis of areas where this evaluation indicates a concern is reserved for future work.

1.4 APPROACH

The U.S. Army Corps, Tulsa District, assembled the multidisciplinary Subsidence Evaluation Team from select federal and state agencies and contractors to perform the evaluation (see Table 1.1, *Subsidence Evaluation Team Organization)*. Besides the multidisciplinary technical team, other team members not having a clearly defined long-term contributing role were to be called upon at the specific times when outside assistance was needed.

The Subsidence Evaluation Team began work in September 2004. A project schedule tied to specific tasks and subsequent meetings was developed to guide the process. The objective was to show relationships between tasks in order to integrate the activities of the Subsidence Evaluation Team members. During the initial meetings, the team formulated a more detailed approach for assessing the potential of future subsidence for the Picher Mining Field. A tour of the site was also conducted by Dr. Ken Luza. Monthly Subsidence Evaluation Team meetings were held throughout the year to discuss progress and technical issues and to resolve issues related to the subsidence study.

A project of this magnitude had never been undertaken for the Picher Mining Field and most available data were not in a form usable by the Subsidence Evaluation Team. For example, a complete inventory of mine maps for the Picher Mining Field had never been undertaken. Over the past 50 years, mine maps had been disseminated to many different locations in several states. One of the first steps was to locate and inventory available mine maps. Maps were located in multiple archives, mining museums, federal and state agencies, and private collections. Over two thousand mine maps of various scales and vintages were ultimately located and inventoried. An ongoing project by the OCC to scan mine maps and microfilm drill-hole logs into digital databases was expanded to include mine maps and logs for this evaluation.

As the study process was further defined, the Subsidence Evaluation Team realized the need for smaller subgroups to address critical needs. Throughout the process, six subgroups to performed specific tasks in support of the subsidence study as detailed below:

- Back-Analysis Subgroup – refine the initial list of variables; select the case study areas for back-analysis; interpret of mine maps, drill logs, and other sources of information to determine and tabulate the values for the selected variables for analysis by the forward analysis subgroup; perform logistic regression analyses to develop a predictive model for subsidence
- Forward-Analysis Subgroup – use variables from back-analysis of past-collapsed and not-collapsed case studies
- Borehole Analysis Subgroup – locate and tabulate drill log information for the analyzed area; determine borehole collar elevations; and interpret borehole logs for depths to geologic units
- Communications Subgroup – prepare briefings; schedule and present the subsidence report to lawmakers and the public
- BLM Mine Map and Geologic Documents Scanning Subgroup – obtain permission; acquire and scan into digital format the BLM (Bureau of Land Management) mine map collection and geologic documents from library repositories nationwide.
- Map Scanning and Acquisitions Subgroup – identify sources; acquire permission and conduct scanning of non-BLM mine maps.

The project also included:

- Interviews with former miners, mining engineers, and surveyors to take advantage of their knowledge of the mine workings and expertise in mine stability in the Picher Mining Field.
- A review of published literature on the Picher Mining Field with selected information incorporated into the database.

TABLE 1.1
SUBSIDENCE EVALUATION TEAM ORGANIZATION

Organization	Team Member
Government Organizations	
U.S. Army Corps of Engineers, Tulsa District	Jonna Polk
	James Martell
U.S. Geological Survey	David Fittermen
	Mark Becker
	Bill Ellis
U.S. Department of Interior, Office of Surface Mining	Len Meier
Oklahoma Conservation Commission	Mike Sharp
Oklahoma Department of Environmental Quality	David Cates
	MaryJane Calvey
Oklahoma Geological Survey	Ken Luza
U.S. Department of the Interior, Bureau of Indian Affairs	Charles Head
Quapaw Tribe	Tim Kent
Contractor Support	
MWH	John Redmond
	Bruce Narloch
	Andrew Rossi
SubTerra, Inc.	Chris Breeds
Keheley & Associates, Inc.	Ed Keheley
Wood Metallurgical Consultants	Frank Wood
Others Contributing to the Evaluation Process	
Oklahoma DEQ	Kelly Dixon
U.S. Department of the Interior, Bureau of Indian Affairs	Bob Coleman
U.S. Army Corps of Engineers, Tulsa District	Adam Crisp
U.S. Department of Interior, Office of Surface Mining	Paul Behum
MWH	John Pellicer
U.S. Department of the Interior	Doug Cook
Miami Integris Baptist Hospital	Dr. Mark Osborne

The large area of the Picher Mining Field and the compressed timeframe in which to complete the subsidence evaluation made it impractical to apply subsidence assessment methods that involved detailed analysis of individual sites. In addition, detailed geologic and rock mechanics information needed to conduct sophisticated analyses and modeling of specific target areas was not available in the amount and at a level of detail needed for a comprehensive evaluation of the entire study area. Therefore, as noted in Section 5, the approach selected for assessing subsidence hazards within the study area was based on an empirical evaluation of factors associated with previous subsidence features located throughout the Picher Mining Field. Previous large subsidence features, as well as non-subsidence areas, were identified and analyzed to determine which of a series of suspected empirical factors provided reasonable correlation with the presence or absence of subsidence. The factors with good correlation to subsidence were applied to target areas within the study area to estimate the relative potential for those areas to undergo a similar large surface collapse. These target areas were identified by a Geographic Information System (GIS) screening model that estimated the amount of potential subsidence based on the combined heights of the underground openings, the depth to the openings, and estimates of the weighted bulking factors for the overburden materials (see Sections 4.5.2 and 6.4).

The USGS served as an active member of the multi-agency Team by providing scientific and technical expertise to the subsidence evaluation process and by participating in the drafting of certain portions this report. However, consistent with agency policy, the USGS did not participate in the development of any recommendations contained within this report and USGS endorsement of any such recommendations should not be implied.

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Insert Figure 1.1 *Overview of study area and Mine Workings*

2 Historical Setting

Underground mine workings showing large piles of ore in the background awaiting removal from the mine.

2. HISTORICAL SETTING

Following is a brief chronology of mine development within the study area and a description of post-mining conditions.

2.1 HISTORY OF MINING IN THE STUDY AREA

The Tri-State Lead-Zinc District in southwestern Missouri and adjoining parts of Kansas and Oklahoma, commonly known as the Tri-State District (Figure 2.1, *Tri-State Lead-Zinc District*), was one of the foremost mining districts in the world. The productive life of the district began with the discovery of lead near Joplin, Missouri, in 1848. A later discovery in Peoria, Oklahoma in 1891 led to the expansion of mining into Ottawa County (Neiberding, 1983). However, the eventual depletion of high-grade ore deposits in the 1930s and the consequent lowering of the grade of mine-run ore caused a gradual and then marked decline in the Tri-State District's output of lead and zinc until the early 1970s when the mining field closed. In most of the intervening years the Tri-State District produced more zinc than any other field in the United States, and it generally ranked third or fourth in the United States in lead production (Martin, 1946).

2.1.1 Ore Discovery and Early Mine Development

The first documented discovery of lead in the Tri-State District was reported near Joplin, Missouri in 1848. With the exception of the Galena area of Cherokee County, Kansas, which was discovered and first mined in the 1870s, and limited mining in the Peoria area of Ottawa County, Oklahoma, mining in the Tri-State District prior to the turn of the century was almost exclusively limited to the Missouri portion of the Tri-State District. Because of this limited scope of mining, the Tri-State District was generally referred to as the Southwest District of Missouri, or Joplin region, until the early 1900s. Southwestern Missouri maintained leadership in domestic metal production through 1917.

The first discovery and earliest mining in Ottawa County was reported in the vicinity of Peoria in Section 12, Township 28N, Range 24E in 1891 (Weidman, 1932). Although there were some subsequent discoveries and mining operations near Quapaw and Commerce in the early 1900s, the real expansion of mining in the Oklahoma portion of the Tri-State District occurred after a major ore discovery at the current site of Picher around 1914 by the Picher Lead Company. Following this discovery, there was a major expansion of mining in what came to be known as the Picher Mining Field of Oklahoma and Kansas. The Oklahoma portion of this field was fairly well defined by the end of 1917, with hundreds of mining companies developing mines (see Figures 1.1 and 2.1). The year 1918 marked an abrupt decrease in production in southwestern Missouri, as operators abandoned the low-grade mines in that part of the Tri-State District and moved their mills to the richer fields in Ottawa County, Oklahoma.

2.1.2 Mining Methods

Mining practiced in the Picher Mining Field is commonly referred to as random room and pillar mining, where rooms were excavated and pillars were left to support the mine roof. However, the mining practice in the Picher Mining Field differed significantly from that in other parts of the United States due to the sporadic, nonuniform ore occurrence and the numerous companies that were involved with mining.

A typical, but by no means comprehensive, sequence of the primary mine cycle events involved:

1. Extensive exploration and laboratory assaying to determine the location and grade of ore within a given parcel boundary.

2. Setting up milling facilities and constructing shafts to access the ore body.

3. Primary mining of rooms while advancing away from the shafts to encounter and remove the high-grade ore. The mining approach was left to the discretion of the underground superintendent (Ground Boss) such

that pillar locations and sizes were a matter of personal experience and not based on any preconceived design. Mining was particularly dangerous as evidenced by the following description of "ladder mining":

> *…"Roof trimming ladders are made of selected spruce in 20-ft sections. When a 5-section ladder is run out, four guy ropes equally spaced with two men to a rope are used to steady the ladder and tilt it carefully back and forth to cover a little more area.", (Eagle-Picher,1943)*

4. As mines became depleted of ore, a second stage of mining was performed by the mining companies, including pillar shaving (trimming) or complete removal of pillars left during primary mining. After the mining companies were finished removing the higher-grade ore, the mine workings were often subleased to independent miners (known as "gougers") who removed the last remnants of ore from the roof, walls, pillars, and floors.

2.1.3 Lead and Zinc Production

Prior to 1918, southwest Missouri maintained leadership in domestic metal production. The output of its mines accounted for more than half of the total domestic production of zinc for several years before 1910. Peak production was reached in 1916 when Missouri produced 53 percent of the lead and 65 percent of the zinc mined in the Tri-State District (Brichta, 1960). In 1918, metal production shifted to the Miami–Picher District as mine operators abandoned the low-grade mines in southwest Missouri for the richer fields in Ottawa County. After 1919, 90 percent of the output of the Tri-State District came from the Picher Mining Field (Martin, 1946). By 1926, 227 mills were operating in Ottawa County.

U.S. Bureau of Mines records indicate that a total of 181,048,872 tons of crude ore (Table 2.1) were extracted from mines within Ottawa County during the period 1891–1970, with approximately 85% of the total production coming from the Picher subdistrict (Joint Response, 1995). A total of 1,686,713 tons of lead concentrate and 8,884,898 tons of zinc concentrate were produced from the crude ore in Ottawa County. The combined lead and zinc concentrates comprised only 6% of the total crude ore mined. The remaining 94% of the crude ore, or 170,185,940 tons, was spread across the landscape in various forms of mill tailings (chat piles, sand piles, flotation fines, and boulder piles).

2.1.4 Mine Maturation and Closure

The outbreak of World War I increased both the demand and prices for zinc and lead, fueling expansion of the Picher Mining Field. The 1920s were the golden years for the Tri-State District, with peak mine production being attained in 1925–1926. During this period, electric power became available throughout the Tri-State District. Mining and milling practices were further advanced with such innovations as the use of central air-compressing plants and the widespread use of froth-flotation in 1924 by the concentrating mills. Zinc and lead recovered by reworking tailings became an important factor in the total production. The flotation process could recover an additional 25 percent of zinc and 10 percent of lead.

The depression years of 1930 to 1939 saw the demand drop for zinc and lead products, with their values being reduced to less than the cost of production. Due to low ore prices in 1931, all but four mines closed and the mining field was allowed to flood. Mine production declined from a high of 10 million tons in 1925 to less than 2 million tons during 1932. Many mining companies could not afford to continue pumping water from the mines during the depression and ceased operations altogether, never reopening some of the mines. Beginning in 1933, the values for zinc and lead began to increase slowly, and by 1939, the district's production was up to about one half its former averages.

World War II once again increased the demand for zinc and lead during the 1940s. Although the federal government froze most prices and wages in 1942, it instituted a "Premium Price Plan" to encourage mining the lower-grade ores. With this plan, mine production again boomed, reaching more than 9 million tons per year during 1943–1944. During World War II, the level of ore production increased, but never duplicated the glory days of the 1920s. After the end of the war, mine production began a slow decline. Although briefly interrupted during the Korean War, the decline continued until 1957, when most of the larger companies ceased operations. In addition, lead usage was coming under attack from poisoning problems related to paint pigments, printer's ink, glass and ceramic ware, and anti-knock gasoline. Zinc use suffered from substitution by plastics, aluminum, and epoxy coatings. The principal market left for lead was the lead-acid storage battery; while zinc continued to be used for steel galvanizing, paint pigments, rubber curing, and die-casting.

By 1959, total crude ore production in Ottawa County was only 15,365 tons. As lead and zinc demand dropped, economic hardship fell upon mining communities of the Tri-State District. In April 1959, a congressional delegation visited the mining area, touring the zinc and lead properties surrounding Picher and visiting the Joplin mining area. The hope was that help from Washington might pump new life into the zinc and lead mines. The grim story of unemployment in the mining field was told before the House Interior Subcommittee in Miami. The testimony given at the hearings by mine operators, miners, business representatives, labor, and social agencies in relating the consequences of mine and mill shutdown had an apparent impact on Congress.

The following year, Congress passed the Small Producers Lead and Zinc Mining Stabilization Act (the Act) to provide an economic stimulus for the Tri-State District. Under the program established to implement the Act, groups of miners formed companies and produced crude ore from many formerly abandoned mines under a subsidy from the federal government. Typically, these companies rented the mining equipment already in place and milled their ore at the central mill or at the sublessor's mill on a toll basis. As a result of this small producers' program, total crude ore production in Ottawa County increased to about 500,000 tons per year during the mid-1960s but decreased rapidly as the program was phased out later in the 1960s. By March 1964, only 281 miners were engaged in the mining industry of Ottawa County (Stroup and Stroud, 1967). By the end of 1967, Eagle-Picher was operating only one mine. Gougers were mining most of the ore. As a result of the selective mining techniques and the lack of discovery of new ore bodies, the Picher Mining Field continued to decline until its final closure in 1970.

2.2 POST-MINING LEGACY

A century of mining operations permanently altered the landscape of the Tri-State District, as described in the following subsections.

2.2.1 Extent of Underground Mine Workings

As described in Section 2.1.3, a total of 181,048,872 tons of crude ore were extracted from mines within Ottawa County during 1891–1970. No industry practices were in place during this period to return processed mill tailings to the subsurface. As a result, mining operations within the district left extensive void spaces in the subsurface. According to Luza (1986), approximately 2,540 acres of the Oklahoma portion of the mining field are underlain by lead and zinc mine workings. Some of the mine workings are as high as 125 feet from floor to ceiling and more than 1,000 feet in length. The extent of subsurface mine workings within the study area is depicted in Figure 1.1 and on a larger scale in separate exhibits that are attached to this report.

2.2.2 Shaft and Non-Shaft Collapses

Surface expressions of subsidence of mine workings in the Picher Mining Field has been classified as due to either shaft related or non-shaft related collapses. A shaft related collapse creates a surface depression larger than the original shaft opening. Shaft related collapses could result from a collapse of cribbing used to hold the shaft open during mining, a collapse of the mine workings at depth in the shaft, or a combination of the two failure modes. A non-shaft related collapse is a subsidence feature formed by the collapse of mine workings in an area where there are no mine shafts. These non-shaft related collapses are generally in areas where mining created high room or stope heights in the mine.

The mining era also left a legacy of open mine shafts, shaft related and non-shaft related collapse features, more than 40,000 exploratory boreholes, hundreds of abandoned deep-water wells drilled into the Roubidoux Aquifer, large areas prone to subsidence, acid mine water discharge from the mines, poor watershed drainage, and millions of tons of mill tailings containing lead, zinc, and cadmium spread over approximately 7,000 acres of the mining field. At least 1,064 mine shafts existed in the Picher Mining Field in northeastern Oklahoma. At the time of the Luza (1986) study, there were 59 major collapses greater than 95 feet in diameter, including both shaft related and non-shaft related collapses. Of these, 29 were major collapses associated with 34 mine shafts and 30 were non-shaft related collapses. More than half of the shafts were concealed or filled, while 481 shafts were either open or in some stage of obvious collapse. Approximately 27 surface acres had been disturbed as a result of shaft related collapses. Some open mine shafts had been filled, mostly by private citizens. Some fencing was installed around a few hazardous sites and the Bureau of Indian Affairs initiated a program to fence all Indian-owned abandoned mining lands under their control.

Of the 30 major non-shaft related collapses inventoried, the largest was a 450 x 320 feet elliptical collapse (2.60 acres) at the Blue Goose No. 1 mine in Section 30, T29N, R23E. Approximately 20 surface acres had been disturbed as a result of non-shaft related collapses.

TABLE 2.1
YEARLY MINE PRODUCTION (TONS) FOR MIAMI-COMMERCE, QUAPAW, AND PICHER SUBDISTRICTS – OTTAWA COUNTY, OKLAHOMA

YEAR	SUBDISTRICT			TOTAL
	MIAMI-COMMERCE	QUAPAW	PICHER	
1907	0	0	0	0
1908	15,000	475,033	0	490,033
1909	91,207	54,546	0	145,753
1910	181,583	40,674	0	222,257
1911	134,560	64,400	0	198,960
1912	202,370	87,829	0	290,199
1913	525,300	55,000	0	580,300
1914	689,987	3,870	0	693,857
1915	613,300	69,200	93,500	776,000
1916	688,100	82,000	616,700	1,386,800
1917	326,500	79,300	3,012,900	3,418,700
1918	85,400	394,700	5,273,800	5,753,900
1919	53,100	730,000	5,206,450	5,989,550
1920	71,000	945,600	5,778,390	6,794,990
1921	8,900	313,300	2,569,400	2,891,600
1922	19,400	1,232,400	4,840,800	6,092,600
1923	99,900	1,653,000	5,971,900	7,724,800
1924	55,200	1,710,400	6,918,500	8,684,100
1925	57,700	1,750,700	8,374,700	10,183,100
1926	126,200	1,726,900	8,028,600	9,881,700
1927	49,400	1,238,300	5,911,000	7,198,700
1928	0	1,367,400	4,160,300	5,527,700
1929	0	1,480,400	4,929,800	6,410,200
1930	4,000	823,700	3,312,900	4,140,600
1931	2,500	160,300	2,043,800	2,206,600
1932	55,000	68,100	1,138,600	1,261,700
1933	30,000	370,100	1,782,100	2,182,200
1934	22,000	496,200	2,048,800	2,567,000
1935	25,000	572,600	2,159,600	2,757,200
1936	15,300	704,400	2,232,900	2,952,600
1937	21,000	502,300	3,264,300	3,787,600
1938	9,200	133,700	2,929,500	3,072,400
1939	11,900	242,100	3,211,900	3,465,900
1940	0	185,929	4,009,471	4,195,400
1941	0	63,442	4,804,579	4,868,021
1942	45,145	441,947	4,525,308	5,012,400
1943	19,013	494,966	4,276,157	4,790,136
1944	6,538	427,455	3,414,678	3,848,671
1945	3,446	270,663	2,957,669	3,231,778
1946	0	208,399	3,434,007	3,642,406
1947	0	90,228	2,672,021	2,762,249
1948	1,310	71,488	2,109,522	2,182,320
1949	0	87,476	2,455,730	2,543,206
1950	5,986	51,378	2,793,516	2,850,880
1951	21,877	204,776	3,315,560	3,542,213

TABLE 2.1(Continued)
YEARLY MINE PRODUCTION (TONS) FOR MIAMI-COMMERCE, QUAPAW, AND PICHER SUBDISTRICTS – OTTAWA COUNTY, OKLAHOMA

YEAR	SUBDISTRICT			TOTAL
	MIAMI-COMMERCE	QUAPAW	PICHER	
1952	25,371	91,652	3,598,306	3,715,329
1953	6,223	53,350	2,039,127	2,098,700
1954	15,632	61,140	2,677,601	2,754,373
1955	9,243	36,106	2,518,266	2,563,615
1956	8,005	61,180	1,686,422	1,755,607
1957	891	49,012	850,070	899,973
1958	991	295	382,910	384,196
1959	0	1,400	13,965	15,365
1960	0	0	19,700	19,700
1961	0	0	80,232	80,232
1962	0	0	349,686	349,686
1963	0	4,199	475,603	479,802
1964	0	7,903	478,042	485,945
1965	0	3,613	591,592	595,205
1966	0	1,813	547,500	549,313
1967	0	5,228	437,600	442,828
1968	0	1,312	274,163	275,475
1969	0	0	97,995	97,995
1970	0	0	72,664	72,664
Total	**4,459,678**	**22,604,802**	**153,767,810**	**180,832,290**

Total Mine Production (Tons) for the Five Subdistricts of Ottawa County, Oklahoma

SUBDISTRICT	CRUDE ORE	CONCENTRATES	
		LEAD	ZINC
Picher	153,767,810	1,453,711	7,238,764
Quapaw	22,604,802	162,563	1,468,961
Miami-Commerce	4,459,678	62,948	172,093
Melrose[1]	191,262	6,480	2,866
Peoria[1]	25,320	1,011	2,214
Total Production	**181,048,872**	**1,686,713**	**8,884,898**

Note:
[1] Not included in annual production summary.

During 2004 and 2005, the OGS updated its inventory of shafts and shaft related and non-shaft related collapses. Since 1982, 15 new shaft related and 20 new non-shaft related collapses have been recorded (see Section 4, Tables 4.1 and 4.2).

Several areas with potential for future subsidence were previously identified during Oklahoma Governor Keating's CY2000 Task Force evaluation of the study area. The list of potential subsidence areas (see Table 2.2, *Potential Subsidence Areas Identified by Retired Miners in CY2000*) was developed by Governor Keating's CY2000 Task Force Subsidence Subcommittee from interviews with former miners during work on the subsidence evaluation.

2.2.3 Groundwater Inundation

During active mine development and production, groundwater that entered the mine workings was pumped to the surface and discharged. As the size of mine workings increased, the overall volume of groundwater entering the mines increased. During peak mining periods, as much as 26,000 gallons per minute of groundwater were pumped in the Picher Mining Field to keep the mines dry.

This water was primarily handled at centrally located pumping stations that were collectively operated by the mining companies. Mining companies began to reduce pumping in 1955, and by 1957 pumping was only occurring on a part-time basis. As a result of these actions, the water level in the southern part of the field had risen by 22 feet by

1968. By 1969, pumping had ceased entirely and all remaining pumps had been pulled from the district. The main body of water in the southern portion of the Picher Mining Field rose 32 feet that year to an elevation of 558 feet. In 1970, water rose another 18 feet in Section 30.

Most of the mines were inaccessible by that time except for those in the northwestern part of the district and some of the upper mine levels. After the abandonment of all pumping operations, complete flooding of the mine workings (approximately 76,000 acre-feet) occurred by 1979.

TABLE 2.2
POTENTIAL SUBSIDENCE AREAS IDENTIFIED BY RETIRED MINERS IN CY2000

1	Tribune newspaper office, Picher—behind office, major underground rock fall goes back to the ball field; west edge of ball field there is a shaft that was filled with wood ties only, then filled with dirt.
2	Black Hawk—pillars shot away in later years. Pull drift leading west to R. Harrell park under which there is an unsupported cavern that the Astrodome would fit into.
3	Center field area of old Tristate Miners ball park—large underground rock fall, roof height 100 feet plus.
4	John Beaver-Crystal-Ritz-up to Velie Lion-all these workings mined to very high roof, sheet ground (shale) unstable plus lower strata made unstable by tar seams.
5	Syndicate—north of pits toward Treece, east of Tar Creek—very bad ground with very thin or no upper limestone supporting strata.
6	Piokee and later Dew Drop mine shaft-removed pillars in later years; a cave-in of east side of Piokee.
7	Lucky Bill to Rialto #1 and #2—pillars removed and totally mined out. Especially around shafts for a 200 foot radius. The roof gets higher toward the Admiralty mine where it was necessary to drill from 75-foot-high tower to reach the mine working face.
8	Humble gravel plant—area under chat pile which includes the Rialto mill shaft lacks support due to absence of supporting limestone, and was mined up to the shale in many areas. Reported early years cave-in south side of chat pile close to old Hwy 69 which filled itself with chat from the tailings pile.
9	Admiralty #1 and #3—unusual geological feature: Miami fault line and anticline visible in the mine; faults known to be prone to slippage.
10 & 11	Beck, southward across east A Street to Hudson mine; cave-in on north side of road, connected underground to location where A Street caved-in to the East.
12	West of Blue Goose #2—caved-in through chat pile years ago, workings unstable and had many roof slab falls during operating years.
13	Goodeagle—although not connected underground to other workings, was mined out on multiple levels to a very high roof.
14	Bendalari and Cherokee—these are in Kansas and had very unstable workings. Former shaft was recribbed 5 times due to poor stability. Typical of mines in the Treece, KS area.
15	Federal Lucky-West of Syndicate—same comments as Syndicate.
16	Howe—West side of tar creek and west of Piokee; had very thin upper strata of limestone, poses threat to Tar Creek if it subsides.
17	New ball park, east edge of street; improperly filled shaft over cavernous area unsupported by pillars.
18	Davis Big Chief & Davis White (later Otis White)—this workings northward and to the southwest was unstable due to tar seams and deposits all the way up to the "E" bed of the Boone Formation.
19	Emma Gordon—mining in commerce area was in very narrow drifts due to nature of ore deposits and lack of good rock overhead for roof support. Room and pillar method less used here.
20	Cactus to Jones & Goldberg—there is a shaft between these two mines not shown on map, right on the section line. Mined area quite shallow and not in stable rock formations probably accounting for present cave-ins.

2.3 MINING LEASES

Pursuant to a treaty of May 3, 1833, the United States conveyed some 150 sections of land on both sides of what is now the Kansas-Oklahoma state line to the Quapaw Indian Reservation. All lands in the Oklahoma portion of the Tri-State District during the period of mining were within the boundary of the original Quapaw Indian Reservation. Under authority of Acts of Congress dated February 8, 1887 and March 2, 1895, the formerly undivided Quapaw Reservation, consisting of 56,245 acres, was allotted to 248 Indians, with 400 acres reserved for school and 40 acres for church purposes (Commissioner's Annual Report, 1920). Stroup and Stroud (1967) state that the reservation was subsequently subdivided into 236 200-acre allotments and 231 40-acre allotments. Each allottee was typically deeded a 200-acre block with inalienable rights for 25 years.

In an Act of June 7, 1897, Congress provided that individual Quapaw allottees could lease their lands without supervision for agricultural or grazing purposes for three years and for mining and business purposes for ten years. Final approval and administration of all negotiated leases resided with the Department of the Interior (DOI), and in many instances, the lands were leased with the assistance and approval of the DOI. Numerous Quapaw allottees also leased their lands for mining purposes without DOI supervision.

A Congressional Act of 1921 stipulated royalty rates for Indian allottees and lease agreements that required "All ores or minerals mined or raised on said land shall be cleaned and prepared for market thereon, and no ore or crushed material shall be removed therefrom to be cleaned, nor shall ore or crushed material from other land be brought or cleaned on said land without the written consent of the superintendent" (U.S. Regulations, 1921). This required a mill to be constructed on each lease. The small leases and the desire for maximum production during periods of high prices resulted in a great number of shafts (often five on a 40-acre tract) (Stroup and Stroud, 1967). The net result of the lease agreements was that more mine shafts were sunk and mills built than were required to mine and mill the ore under a different lease arrangement. In addition, the lease arrangements required that all mill tailings be left on the lease, which resulted in mill tailings in all forms being indiscriminately spread across the mining field. By the 1930s, there were approximately 150 chat piles of various sizes in the Picher Mining Field.

During the overall mining period, an average of 25 percent of the lead and zinc produced in the Picher Mining Field came from land owned by individual Indians (Williams, 1930). Few individual mining companies had the capital or other resources to comply with the standard terms and conditions for a 200-acre allotment. As a result, royalty companies, large mining companies, or individual promoters and speculators acquired most initial leases with the Quapaw landowners. These arrangements eventually led to the subdivision of 200-acre allotments into 20- to 40-acre parcels (Stewart, 1984). In the early years, all of these deals were usually in the form of handshake agreements, and as such they were never placed in the public record.

2.4 REGULATORY OVERSIGHT OF MINING OPERATIONS

Federal and state regulators provided little oversight of mining operations on non-Indian lands during the mining years. All mining operations were under the Oklahoma State Mining Code. Prior to 1920, the state of Oklahoma developed an elected position of State Mine Inspector who had authority only on non-Indian lands in Ottawa County. The local mine inspector was elected by popular vote, rather than selected based on qualifications. Prior to 1965, the U.S. Bureau of Mines primarily provided professional mining services to the BIA rather than enforcement of safety regulations. Federal inspection of mines on Indian-owned lands by the U.S. Bureau of Mines Health and Safety Division became effective in 1965.

Prior to the act of 1921, the DOI did not exercise supervision through the Quapaw Agency of lead and zinc production from mines on Indian lands on the Quapaw Indian Reservation. The reconstruction of production records prior to 1921 later proved difficult; no data were available at the Quapaw Agency relative to the production of ore from the old Peoria and Lincolnville camps, or for production from the Miami and Picher camps prior to 1917 (Williams, 1930). The Miami field office of the U.S. Geological Survey (USGS) was established under a cooperative agreement with the Office of Indian Affairs in 1923. Under the agreement, the USGS provided the first oversight of mining operations on Indian-owned lands. Detailed records of production, sales, and royalty-leased and subleased mines were maintained from that date forward.

The major safety concerns in the mines, aside from falling rocks and unsafe handling of dynamite, were excessive mining of the mine roof, and trimming and removing support pillars. Throughout the mining period, it was a common practice of the mining companies to remove or trim any pillars that contained high levels of lead and zinc before the mines were abandoned (Eagle-Picher, 1943; Weidman, 1932). The decision to remove or trim supporting pillars was made primarily by the mine operators without approval of the state or federal mine inspectors. Around 1950, the few remaining large mine and/or mill operators who still operated mills began to sublease less productive mines to small independent mine operators, who would mine the last remaining ore and sell it to the mills. The small operators would often lease the mining equipment left underground by the larger mining companies.

A formal process was established to control pillar removal on Indian-owned lands by the USGS and the U.S. Bureau of Mines (USBM) (Westfield and Blessing, 1967). A three-member committee of representatives from the USGS, USBM and the Oklahoma State Mining Inspector was established. Mine operators were required to request advance permission from the committee to trim or remove pillars. Each pillar request was evaluated by the committee, and a determination was made based on the safety considerations of removing or trimming the pillar. The committee was in place until 1970, when the mining operations ceased.

2.5 SECTION 2 REFERENCES

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Insert Figure 2.1, *Tri-State Lead Zinc District (modified from Bricta, 1960)*

3 Study Area Conditions

A view of the 1.5 acre mine collapse that occurred in Picher in 1967. The mine workings collapsed 25 feet below the ground surface.

3. STUDY AREA CONDITIONS

3.1 TOPOGRAPHY AND CLIMATE

The eastern part of the Oklahoma portion of the Picher Mining Field (the Peoria Camp) is situated on the west edge of the Ozark Plateau province. The Ozark Plateau is a broad, low structural dome lying mainly in southern Missouri and northern Arkansas. However, the main part of the Picher Mining Field is within the Central Lowland province. A nearly flat, treeless prairie underlain by Pennsylvanian shales characterizes this province.

The streams that traverse the mining field flow southward to the Neosho River and are slightly incised below prairie level. Elm Creek, on the western edge of the Picher Mining Field, and Tar Creek and its main tributary, Lytle Creek, are the principal streams in the main productive part of the Picher Mining Field. Elm, Tar, and Lytle creeks furnished some water for the mill operations, although most mill water was pumped from the mines and/or from deep wells. A short distance east of the Picher Mining Field is the Spring River, which is the major south-flowing tributary of the Neosho River. The physiographic boundary closely parallels the Spring River: the region east of the river is hilly, moderately dissected by through-going streams; whereas to the west, the terrain is nearly level prairie.

Topographic relief in the mining field is relatively small. The lowest point, south of Commerce, is about 780 feet above mean sea level. From Commerce, the land rises gradually to the east to an average elevation of 830 feet above mean sea level. The highest point in the field is in the eastern part (Section 30, T29N, R24E), at 900 feet above mean sea level.

The normal annual precipitation at Miami, Oklahoma, about 7.5 miles southwest of Picher is 44.85 inches, but yearly totals have ranged from 19.89 inches (1963) to 66.9 inches (1973) (Oklahoma Climatological Survey). The heaviest precipitation comes during the spring, but September and October are also wet. Winter is the driest season. January, the driest month, has an average annual precipitation of 1.65 inches (based on the 1971–2000 average).

The mean annual temperature at Miami is 57.6°F (based on the 1971–2000 average). July is the hottest month, and January the coldest. The highest temperature recorded in Miami was 116°F on July 14, 1954; the lowest temperature recorded in Miami was –25°F on January 22, 1930 (Oklahoma Climatological Survey). The average growing season, from the last killing frost in the spring to the first in the fall, is 200 days. Average annual snowfall in Miami is 10 inches. Snowstorms are usually of short duration, and the snow remains on the ground only a few days.

3.2 REGIONAL GEOLOGY

The geologic framework and origin of the lead and zinc deposits have been discussed by numerous authors. These publications include Siebenthal (1908), Weidman *et al.* (1932), Reed *et al.* (1955), Brockie *et al.* (1968), and McKnight and Fischer (1970). The Picher Mining Field straddles the Cherokee Platform–Ozark Plateau.

The rock formations exposed at the surface in the mining field include Mississippian and Pennsylvanian rocks that are nearly flat, with a low, regional northwestward dip of about 20 to 25 feet per mile (Figure. 3.1). Cambrian and Ordovician formations, primarily dolomite and chert with some sandstone and minor shale, are encountered only in deep drill holes and water wells in this area.

Mississippian rock units, principally the Boone Formation, are the host for most of the ore deposits. The Boone Formation is composed of fossiliferous limestone and thick beds of nodular chert. The term "Boone" is commonly used to describe the sequence of Mississippian interbedded limestone and chert units that crop out in northeastern Oklahoma. The Boone Formation, which is 350 to 400 feet thick in the Picher area, is subdivided into seven members (in ascending order): St. Joe Limestone, Reeds Spring, Grand Falls Chert, Joplin, Short Creek Oolite, Baxter Springs, and Moccasin Bend (McKnight and Fisher, 1970). Fowler and Lyden (1932) and Fowler (1942) further subdivided these members into 16 beds. Letters of the alphabet were used to distinguish individual beds, beginning with *B* near the top of the Moccasin Bend member and ending with *R* in the Reeds Spring member (Figure 3.2).

The Quapaw Limestone near Lincolnville and in part of the main Picher Mining Field overlies the Boone Formation. The Chesterian Series, represented by the Hindsville Limestone, Batesville Sandstone, and Fayetteville Shale, generally forms a disconformable contact with the Boone Formation and/or Quapaw Limestone. Chesterian rocks are exposed on the east side of the Picher Mining Field. However, the Batesville Sandstone and Hindsville Limestone also outcrop near Douthat (Section 29, Township 29N, Range 23E). Both the Hindsville and Batesville are locally mineralized, especially in the eastern part of the mining field near Lincolnville.

Pennsylvanian formations of the Krebs Subgroup (the lower division of the Cherokee Group) overlie the Boone Formation. The Krebs Subgroup was deposited on a post-Mississippian erosional surface. The formations, as mapped by Branson (Reed *et al.*, 1955), include the McAlester Formation, the Savanna Formation, and the basal Bluejacket Sandstone Member of the Boggy Formation. These formations consist of alternating terrestrial fine-grained sandstone, shale, and thin coal beds. The sandstone units are discontinuous and vary significantly in thickness where they are laterally continuous.

Drillers' logs were used to characterize the site geology at the individual mine leases studied in this report. The logs were used to group geologic formations that had similar lithologies and engineering properties into three categories. The Krebs Subgroup units, Fayetteville Shale, and Batesville Sandstone were grouped into a category called "shale". The first occurrence of limestone on a driller's log was called the top of the "Chester". This category included the Hindsville and Quapaw Limestones. The first occurrence of flint and/or chert on a driller's log was used to determine the top of the Boone Formation.

3.3 ORE DEPOSITS

The ore deposits in the Picher Mining Field occur mainly in the upper half of the Boone Formation. A majority of the mine workings are within the *M* bed. Other important ore zones occur within the *K*, *G*, *H*, and *E* and Chester beds, and "sheet ground", or low-grade blanket deposits, occur within the Grand Falls Chert Member (generally corresponds to the *O* bed).

Nearly all the ore bodies in the Picher Mining Field are tabular masses whose horizontal dimensions exceed their thickness. Some ore bodies are blanket-like bodies, dominantly irregular or lobate in plan, but tend to be slightly elongated and curved. These bodies grade into others, called "runs," which are flat, narrow, elongate, and usually curvilinear. Many of the runs tend to form closed but irregular-shaped circles around barren cores. Some runs are vertical and vary from 10 to 15 feet wide and over 100 feet high. Vertical runs have steeply inclined walls and generally follow near-vertical fracture zones in the rocks. Some of the smaller ore bodies, called "pockets," have a somewhat circular shape. They are usually separated from the main ore body by slightly mineralized and/or barren rock. Many of the ore pockets occur in highly brecciated rock locally described as "boulder ground." Boulder ground is composed of silicified and/or dolomitized blocks of fracture rock, one to five feet in diameter, cemented by ore and gangue minerals (Weidman *et al.*, 1932; McKnight and Fischer, 1970).

Most of the ore bodies are largely confined to a definite stratigraphic interval; so the tops and bottoms of the ore bodies are therefore crudely parallel. Stopes in bodies of this type are commonly 10–20 feet high. Where two or more stratigraphic units contain ore bodies that are superposed or partly overlap, they are mined together, and in such places stopes may be 50 to 100 feet high. If the ore-bearing units were separated by much waste rock, they were mined at separate levels (McKnight and Fischer, 1970).

The chert within the Boone Formation was structurally deformed and shattered prior to mineralization. Much of the ore is in the matrix of a chert breccia. The limestone that originally formed this matrix was either removed by leaching or was entirely replaced by the ore and gangue minerals. The ore consists of sphalerite, galena, dolomite, and jasperoid, with an unreplaced residuum of chert. Accessory metallic minerals are chalcopyrite, enargite, luzonite, marcasite, and pyrite. Considerable amounts of calcite and some quartz and barite occur in the ore. The zinc-to-lead ratio for the ore, based on the total production of the field, was about 4.1:1 (McKnight and Fischer, 1970).

3.4 GEOLOGIC STRUCTURE

At a few places in the Picher Mining Field, sharply defined structural features are accompanied by appreciable dips. The Miami Trough, Bendalari Monocline, and Rialto Basin are three prominent structures that dominate the main part of the Picher Mining Field. The Miami Trough is a combination syncline and graben that crosses the western part of the Picher Mining Field with an average trend of N 26^{o} E. The width of this structure is 300 to 2,000 feet, averaging about 1,000 feet. The maximum vertical displacement is about 300 feet. The Bendalari Monocline crosses the mining field with a northwest strike and drops the mineral-bearing ground a maximum of 140 feet on the northeast side. The maximum dip is about 20^{o}. Chesterian strata are preserved in greater thicknesses on the down-dropped side, and the structure is hardly noticeable in Pennsylvanian strata. The Rialto Basin is an irregular, east-trending, faulted syncline nearly a mile long and as much as a quarter of a mile wide. It has a maximum displacement of 80 feet and contains a thicker sequence of Chesterian strata than is found in areas outside the basin (McKnight and Fischer, 1970).

The linear structural features, such as the Miami Trough, are of tectonic origin and probably have been modified by some dissolution of carbonate rocks at depth, resulting in additional subsidence. The Rialto Basin and smaller basins may have developed where dissolution along deep-seated fractures was accompanied by subsidence (McKnight and Fischer, 1970).

3.5 SEISMICITY

The Picher Mining Field is considered to be in a regional "seismic cold spot" according to the USGS seismic hazard model, with a probability of less than 0.01 (1 chance in 100) of experiencing an earthquake of magnitude (M) 4.75. Significantly lower probabilities are associated with higher-magnitude earthquakes.

The USGS National Seismic Hazard Mapping Project (NSHMP) computes estimates of peak horizontal ground acceleration (PGA) and spectral acceleration (SA) that have a specified probability of being exceeded in a given time interval. Typically, the time interval chosen is 50 years, although other intervals may be considered. Two probabilities that are available in the NSHMP documentation, Frankel *et al.* (2002), are a 2% and 10% probability of exceedance (PE) in 50 years.

For sites in the vicinity of Picher, Oklahoma, the estimated seismic hazard is quite low in the sense that the 2% PE in 50 years ground accelerations are expected to be low compared to most other locations in the U.S. Table 3.1, *2% in 50 Years PE Accelerations for Picher, OK Region: 94.85˚W,37˚N*, shows the 2% PE in 50 years motions for a site very near Picher on the Oklahoma-Kansas border (nearest grid point to Picher where these probabilities were calculated).

TABLE 3.1
2% IN 50 YEARS PE ACCELERATIONS FOR PICHER, OK REGION: 94.85°W, 37° N

Motion	Probable Acceleration (g)
PGA	0.059
1 Hz SA	0.071
5 Hz SA	0.142
10 Hz SA	0.127

The motions in Table 3.1 correspond to acceleration on a rock site with assumed shear-wave velocity of 760 meters per second in the upper 30 meters. This velocity is roughly equivalent to the National Earthquake Hazards Reduction Program's B (rock)-C (very dense soil or soft rock) boundary. For perspective, a horizontal PGA of about 0.2 g is generally required to knock objects off shelves; 0.1 times the value of gravity is sometimes used as an approximate lower limit for damage to unreinforced masonry such as brick chimneys. Such estimates are rough, and local site conditions will affect any estimated damage distribution. Figure 3.3 is a map of the probability of experiencing, in any 100-year period, an M 4.75 or greater earthquake within 50 km of each site on the map. Picher, located at the center of the map, is in a regional "seismic cold spot" according to the USGS seismic hazard model, with a probability of less than 0.01 (1 chance in 100) of experiencing such an earthquake.

According to the USGS model (Frankel *et al.*, 2002), most of the seismic hazard at Picher is posed by distant seismic sources, in particular, the New Madrid Seismic Zone (NMSZ), about 260 miles east of Picher. Large magnitude seismic events on the NMSZ have an expected recurrence interval of about 500 years and an estimated typical magnitude of about **M** 7.7. A very small contribution (about 1%) of the seismic hazard also comes from the Meers Fault in southwest Oklahoma. This fault zone, at about the same distance from Picher as the NMSZ, has a much longer mean recurrence interval, and the maximum credible earthquake is estimated to be smaller (about **M** 7.0) than the NMSZ main shocks. Because Meers Fault earthquake would typically be of lesser magnitude and longer frequency than New Madrid events, its contribution to the seismic hazard is very small.

Another possible source zone that potentially affects the seismic hazard in northeast Oklahoma is the Saline River source zone (SRSZ) in east-central Arkansas. This source zone is currently considered to be somewhat speculative, and for this reason was not specifically included in the USGS seismic hazard assessment of Frankel *et al.* (2002). Evidence from paleoseismology includes sand blows and dikes in cutbanks in Ashley and Desher counties, but this evidence cannot be conclusively associated with the postulated SRSZ (Cox *et al.*, 2004).

In conclusion, the seismic hazard in the Picher, Oklahoma area is considered to be very low according to the USGS seismic hazard model, with a probability of less than 0.01 (1 chance in 100) of experiencing an earthquake of magnitude 4.75 or greater within any 100–year period.

3.6 HYDROLOGY

Groundwater is the primary source of water within the study area. Three primary aquifers are present within the study area. Two of the aquifers, the Boone and the Chat, are shallow and the water is not potable. The recently identified Chat Aquifer is an artificially created, unconsolidated surficial aquifer composed of mine tailings distributed over much of the Picher Mining Field (Becker, 2005: personal communication). Thicknesses range from just a few feet to several hundred feet where large piles still exist. Recharge over the Chat Aquifer is rapid due the relative textural homogeneity and unconsolidated nature of the material. Base flows in Tar and Lytle creeks are generally sustained through the mining area by discharge from this surficial deposit. However, most of the domestic, municipal, and industrial supply is from the deep Roubidoux Aquifer.

The Roubidoux Aquifer underlies the Boone Aquifer and is generally a fractured cherty dolomite interbedded with thin sandstones. Uppermost portions of the Roubidoux Aquifer are less permeable, which therefore restricts vertical movement of water from the Boone into the Roubidoux Aquifer. Large municipal and industrial withdrawals have lowered the water levels in the Roubidoux from pre-pumping levels where wells were artesian to 300 to 500 feet below land surface. Roubidoux supply wells in the mining area are often drilled to a depth of 900 to 1,100 feet and are cased to the base of the Boone Aquifer. Water was withdrawn from the Roubidoux Aquifer when mining was active to supply mills and flotation-separation activities.

The Boone Aquifer consists of the Boone Formation where most of the ore occurred. Large amounts of water were withdrawn from the Boone Aquifer to allow for access to the ore deposits during the period when the Picher Mining Field was being mined. Cessation of dewatering activities resulted in the recovery of water levels to their current elevations above the mine-roof elevations. The equilibrium of water levels has been maintained through discharges from mine shafts, vent holes, abandoned wells, and exploration holes whose openings to land surface are below the water level elevation of the Boone Aquifer. Groundwater elevations in the Boone Aquifer indicate a very subtle north to south gradient. Recharge to the Boone Aquifer occurs rapidly following precipitation and continuous recording wells in the mine workings indicate that the mines are hydraulically connected with elevations generally maintained at 795 to 805 feet above mean sea level.

Groundwater movement between the Boone and Roubidoux aquifers was likely minimal prior to mining activity. However, it is estimated that hundreds of water supply wells were drilled through the Boone Formation and into the Roubidoux Aquifer to supply mills and towns with good-quality water. Due to the current elevation differences of water levels between the Boone and Roubidoux aquifers, there is a downward flow gradient. Over time, casings and cement seals in the Roubidoux wells will become compromised and allow contaminated mine water from the Boone Aquifer to flow into the wells and then downward to contaminate the Roubidoux Aquifer. The EPA and ODEQ have been working since the 1980s to locate and plug these wells. Open mine shafts and subsidence features in the area used for the dumping of trash are an additional potential source of contamination to the Boone Aquifer.

3.7 SECTION 3 REFERENCES

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Insert Figure 3.1, Regional Geology

Insert Figure 3.2, Geologic Map

Insert Figure 3.3, Earthquake Probability

4 Mine Subsidence

A mine inspector viewing the damage caused by 1967 mine collapse in Picher.

4. MINE SUBSIDENCE

There are two primary categories of subsidence associated with underground mining. The first category is called "chimney", or "plug" subsidence, and is characterized by shearing, steep-sided depressions, and large-differential displacements. The subsidence features formed by this mode of subsidence are commonly referred to as sinkholes, but the term "chimney subsidence" is used in this report to differentiate mine subsidence events from naturally occurring sinkholes that form in karstic limestone deposits. Mine roof failure may or may not propagate to the surface to form chimney subsidence depending upon several factors, including the depth and height of the underground opening, the strength characteristics of the immediate roof and overlying rock mass, and the bulking characteristics of the overlying rock mass.

The second category of subsidence is termed trough subsidence, and is typically characterized by a broad, shallow, trough-shaped depression that forms above a mine opening when the overlying strata sag into the mine void with minimal shear displacement. This type of subsidence is commonly associated with longwall coal mining, where a very wide area of coal (300 to 1,000 feet), called a panel, is extracted without leaving pillars or artificial support and the overlying material is allowed to displace downward into the mined panel behind the advancing mine face. The potential for trough subsidence over room and pillar mines is dependent upon the stope geometry (width, length, and depth), extraction ratio, and the stability of the mine pillars, roof, and floor. Although it is likely that trough subsidence has occurred in the Picher Mining Field, it is currently not well recognized or mapped. Chimney subsidence is considered to be the primary category of subsidence in the study area, and by its nature imposes the greatest hazard to public safety.

There are two types of subsidence features that have been widely observed throughout the Picher Mining Field and in the study area – shaft related and non-shaft related subsidence. Non-shaft related subsidences are believed to be predominantly of the chimney category that result from the collapse of mine workings. This section of the report discusses these subsidence types in greater detail, summarizes the primary factors influencing subsidence, provides a brief overview of available subsidence analysis methods, and introduces the subsidence evaluation method chosen for application in the study area.

4.1 TYPES OF SUBSIDENCE IN THE PICHER MINING FIELD

The random room and pillar mining method used in the Picher Mining Field resulted in the excavation of irregular shaped stopes, or rooms, and interconnected underground haulage ways that were ultimately abandoned as mining in the area ceased. Often these stopes were quite large in both lateral dimension and height. The presence of such large excavations at relatively shallow depths made the areas above the stopes vulnerable to subsidence in the event of collapse of the underground workings. Pillar shaving and removal that was commonly practiced during the late stages of mining to recover economical ore resulted in unusually high extraction ratios for room and pillar mining and increased the potential instability of the excavations. Later pillar shaving, pillar removal, and mining of small pockets of ore by independent miners further aggravated the stability of the mine workings and increased the potential for subsidence.

Because of the widespread mining activities, the large number of mining leases, and multiple mining companies involved in mining the Picher Field, a large number of abandoned mine shafts are also present throughout the study area. Many of these mine shafts have collapsed in the past, and remaining shafts are prone to future failure and subsequent subsidence.

4.1.1 Shaft-Related Subsidence

Three stages of shaft related collapse and subsequent subsidence have been described in the Picher Mining Field (Luza, 1986) and are depicted in Figure 4.1. Figure 4.1a shows an operating shaft that is timber lined through the relatively incompetent overburden (e.g., alluvium and shale) and extending to the mine floor. The shaft is not lined where it passes through the more competent portions of the overburden (e.g., limestone and chert). Two or more mine pillars were typically left around the base of the shaft (Figure 4.1b) to provide extra support and prevent shaft failure and subsidence during active use. After mining ceased in a given area and a shaft was no longer required for access or ventilation, it was typically abandoned. Figure 4.1b shows an intermediate stage of shaft collapse, where the upper support timbers have rotted out or been removed, and Figure 4.1c shows a later stage of collapse where the lining has completely failed and the weak overburden has collapsed to fill the shaft. This type of subsidence may or may not be coupled with stope roof failure (see Figure 4.1d), as discussed below.

The shaft failure sequence shown in Figure 4.1 also illustrates the impact of surface drainage on the shape and size of a subsidence feature, where the erosion of exposed rock and/or alluvium will, with time, increase the lateral dimensions of the subsidence.

4.1.2 Non-Shaft Related Subsidence

The majority, if not all, of the non-shaft related collapses in the Picher Mining Field are associated with progressive collapse of the mine roof, either as the roof span was increased during primary mining or where pillars were removed during secondary mining. Figure 4.2 illustrates the various stages of mine roof failure associated with this type of subsidence.

Non-shaft related subsidence events in the study area have been reported from hours to years after mining has ceased, and such subsidence continues to occur in the Picher Mining Field as described in Section 2. A recent collapse at the Skelton lease near Highway 69 south of Picher is thought to be an example of this type of collapse. There currently is no reliable method to accurately predict when such subsidence events will occur.

4.1.3 Coupled Shaft Related and Non-Shaft Related Subsidence

A third, hybrid, type of subsidence, where pillars were removed from around abandoned shafts by gougers who accessed the underground workings from adjacent mine leases, has been observed. This practice typically led to direct subsidence of the surface and, in at least one case, resulted in the formation of a very large subsidence area (Keheley, 2005: personal communication).

4.2 RECENT SUBSIDENCE OCCURENCES

Subsidence has continued above the mine workings in the Picher Mining Field from shortly after the onset of mining to this day. Luza (1986) compiled an inventory of shaft related and non-shaft related collapses that occurred prior to 1982. An inventory of shaft collapses and non-shaft related collapses that have occurred since 1982 has been maintained by one Subsidence Evaluation Team member (Keheley, 2005), and is reproduced in Table 4.1 and Table 4.2. These later collapses tend to be smaller in size than many of the collapses that occurred prior to the end of mining in the area.

The mine related surface impacts outlined above occur throughout the lead-zinc mining areas of Oklahoma, Missouri, and Kansas and have been investigated, characterized, and catalogued over the 35-plus years since mines in these areas were abandoned. The extensive survey of mine subsidence features in the current study area, originally published by Luza (1986), has recently been updated with location information incorporated in this study. However, there is little published information regarding subsidence analysis or subsidence prediction in the Picher Mining Field, and there has not as yet been an attempt to complete a systematic analysis of subsidence potential in the study area.

TABLE 4.1
PARTIAL LIST OF SHAFT-RELATED COLLAPSES
IN THE VICINITY OF PICHER-CARDIN-HOCKERVILLE SINCE 1982

Case Number	Shaft Related Collapse
1	Sooner tailings pile shaft No. 5-Dec. 2001. S16 T29N R23E.
2	Velie Lion shaft No. 37-Between 1982 and 2000. Elliptical collapse-approx. 60 x 80 feet x 35 feet deep. S19 T29N R23E.
3	Harrisburg shaft No. 44-Dec. 2002. Circular collapse expanded to approx. 80 feet in diameter x 70 feet deep. Collapse remains active. S19 T29N R23E.

TABLE 4.1 (Continued)
PARTIAL LIST OF SHAFT-RELATED COLLAPSES
IN THE VICINITY OF PICHER-CARDIN-HOCKERVILLE SINCE 1982

Case Number	Shaft Related Collapse
4	Craig Lease Shaft No. 20- Dec 2003. Circular collapse 12 feet in diameter x 4 feet deep. S33 T29N R23E.
5	Craig Lease shaft No.15- Partial collapse 2002-12 feet in diameter x 4 feet deep (North side of lease in pasture adjacent to E40 Rd.). S33 T29N R23E.
6	Warner Fee (Commerce) Shaft No.1-January 2005. Circular collapse 10 feet in diameter. S6 T28N R22E.
7	Beck shaft No. 16-partial collapse beginning in 2001- 10 feet diameter x 8 feet deep. The shaft has continued to deepen. S29 T29N R23E.
8	Lucky Jenny shaft No. 11 (Hockerville)-late 2004 or early 2005. Circular collapse 50 feet diameter x 40 feet deep. S14 T29N R23E.
9	Mahutska Lease shaft No. 10 in the tailings pile-between 1982 and 2004. Circular collapse in tailings pile approx. 60 feet in diameter. S21 T29N R23E.
10	Partial collapse of Shaft No. 31 on the Barbara J Lease adjacent to Hwy 69-Occurred in 2001. Circular collapse 10 feet in diameter x 6 feet deep. S29 T29N R23E.
11	Shaft No. 34 fill material collapsed on the Beck Lease adjacent to 'A' Street. Concrete collar intact. Date unknown. S15 T29N R23E.
12	Shaft No.17 on the Missouri Mule Lease-Occurred around 2000. Circular collapse 20 feet in diameter. Water level 10 feet from surface. S28 T29N R23E.
13	SHAFT No. 10 on the New Chicago No. 2 Lease-Occurred in 2002. Circular collapse 20 feet in diameter x 15 feet deep. S28 T29N R23E.
14	Shaft No. 19 on the Ritz Lease in the road on Ash Street, south of Cardin Road, one block south of the old Eagle-Picher Office/Shop site. Occurred 1982. Approx. 40 feet in diameter x 30 feet deep. S30 T29N R24E.
15	Unnumbered shaft adjacent to Hwy 137 in Quapaw. Occurred in 2003. Approx. 15 feet in diameter x 30 feet deep. S35 T29N R23E.

TABLE 4.2
PARTIAL LIST OF NON-SHAFT
RELATED COLLAPSES IN THE VICINITY OF PICHER-CARDIN-HOCKERVILLE SINCE 1982

Case Number	Non-Shaft Related Collapse
1	Scammon Hill- Near shaft No.12- small elliptical collapse adjacent to collapsed shaft. Approx. 20 feet In diameter x 8 feet deep. S36 T29N R22E.
2	Scammon Hill- Near shaft No. 8-small circular collapse near shaft. Approx. 30 feet in diameter x 15 feet deep. S36 T29N R22E.
3	Massel Lease-two small collapse features adjacent to mill concrete pillars. Approx. 20 feet in diameter x 15 feet deep. S23 T29N R23E.
4	Scott Lease-Circular collapse 20 feet diameter x 10 feet deep. Water level at 10 feet-Jan. 2003. S13 T29N 23E.
5	Howe tailings pile-circular recollapsed around 1997. Expanded to 42 feet in diameter by 2001. S17 T29N R23E.
6	Drill hole collapsed in James Cruzan's yard in Picher-2004. Approx. 6 feet x 8 feet S17 T29N R23E.
7	Collapsed drill hole on the Ruth Goodeagle lease approx. 100 yards. SE from shaft No. 3. Occurred in 2003. Approx. 2 feet x 8 feet S34 T29N R23E.
8	Elliptical collapse in the pasture 100 yards. east of S590 Road. Occurred in 2003. 12 feet x 15 feet by 10 feet deep. Collapse continues to increase in size. Also a drill hole collapse 100 feet NW of the elliptical collapse. S34 T29N R23E.
9	Martha B Mine, State Line Road-8 feet collapse 4 feet deep-January 29, 2005. Large depression 25 feet in diameter x 2 feet deep adjacent to the collapse. May be karst feature? S17 T29N R24E.

TABLE 4.2 (Continued) PARTIAL LIST OF NON-SHAFT RELATED COLLAPSES IN THE VICINITY OF PICHER-CARDIN-HOCKERVILLE SINCE 1982	
Case Number	Non-Shaft Related Collapse
10	Small collapse in S590 Road on the Dardene Lease between Sections 21/22 T29N R23E. Approx. 4 feet in diameter x 8 feet deep-2004. Collapse filled with boulders by the County road crew.
11	Collapse 1531 on the Consolidated Lease west of Commerce. Filled after 1982. In a state of major collapse in 2005. S1 T29N R22E.
12 .	Circular collapse 100 yds. Northeast of Velie Lion mill site-70ft in diameter x 30 feet deep. S19 T29N R23E
13	Collapse on the J. E. McGuirk Lease on the north side of E40 Road (Blue Hole Road) – Occurred Approx. 1982. Approx. 30 feet in diameter by 15 feet deep. Rural water system had to be permanently rerouted around the opening. S30 T29N R24E.
14	Large collapse 300 feet west of police station in Commerce-50 feet wide x 70 feet long x 140 feet deep. 1994-1995. S1 T29N R22E.
15	North side of 'A' Street 1.5 miles east of Picher-1992. Size unknown.
16	Small circular collapse on the Alice Greenback Lease adjacent to Hwy 69A NE of Quapaw. Approx. 4 feet diameter x 6 feet deep. Hole collapsed 3 times in 2004. S26 T29N R23E.
17	Old Hwy 66 in Commerce at the intersection of current Main Street and "C" Street-Drill hole in the center of the road 6 feet wide x 22 feet deep 1994. S1 T29N R22E.
18	Small circular collapse on the Skelton Lease adjacent to Hwy 69 on the east side, south of Picher- March 2005. Approx. 12 feet in diameter x 6 feet deep. S28 T29N R23E.
19	Circular collapse in S ½ of SE ¼ of Section 20 T29N R23E-5/8/83. Approx. 60 feet in diameter x 30 feet deep.
20	Circular collapse in the Ritz chat pile on the Ritz Lease, July 2005. Approx. 12 feet in diameter x 20 feet deep. S30 T29 R23E.

4.3 MECHANICS OF MINE ROOF FAILURE AND SUBSIDENCE

The following generalized description of mine roof failure is intended to provide a non-technical explanation of the mine collapse processes believed to be responsible for non-shaft related subsidence in the Picher Mining Field and the study area. A detailed account of mine roof failure mechanisms and the theoretical basis for roof failure analyses is beyond the scope of this report, but detailed theories on mine roof failure and stability analysis can be found in numerous publications (e.g., Brady and Brown, 2004; Obert and Duval, 1967).

In general, the mine roof and overlying strata in a horizontally or near-horizontally bedded rock mass can be considered as a sequence of plates (in three dimensions) or beams (in two dimensions). The thickness of each plate or beam is determined by the geologic contacts between rock units of similar strength and mechanical properties. The thickness of each bed and the rock strength determine the overall strength of the plate or beam. Geologic layers that bond to overlying or underlying strata of similar properties can be grouped as thicker, and thus stronger, plates or beams. A simple beam analogy is the use of multiple layers of lumber to form load-bearing headers above windows or doors in home construction. As an opening is developed underground, the width and length of the unsupported roof increases. If the opening dimensions get too large, the immediate mine roof (e.g., the first layer of rock) cannot support itself and fails. Obviously, more competent roof materials and more massive and continuous strata allow wider rooms to be excavated without roof failure.

Prior to mining, rock at the mining level is subject to both a vertical stress due to the weight of the overlying rock (gravity load) and a horizontal stress that results from the rock's reaction to the vertical stress. These stresses may or may not be modified by tectonic activity, rock dissolution, or other geologic processes.

During and after excavation of an underground opening, stresses can not be transmitted through the void that is created, and vertical stress is transferred to the adjacent rock that forms the sides of the opening. This stress transfer is commonly conceptualized as occurring through a pressure arch that forms above the opening in the overlying rock mass (see Figure 4.2a). Thus, the load carried by the immediate roof is limited in that it carries only its own weight and some portion of the weight of material below the pressure arch, but does not carry the total overburden load.

This same concept applies to room and pillar mining when the pillars are too small (either by design or by shaving and/or removal of adjacent pillars) to carry the total overburden load. Under high loads relative to the strength of the pillars, the pillars deform or yield, resulting in stress transfer and the extending of the pressure arch to the sides of the opening or to larger adjacent pillars (see Figure 4.2b). This process is believed to be why some very wide rooms that were developed during primary and secondary mining in the study area have apparently not collapsed.

As the dimensions of the underground opening increase, the pressure arch increases in height. During this process, the thickness of rock supported by the pillars under the pressure arch increases, causing increased pillar stress. As the room width and corresponding height of the pressure arch increase, the pressure arch ultimately intersects the weaker, overlying strata (i.e., the shales, sandstones, and alluvium in the study area). Because these weaker materials cannot effectively support a pressure arch, the pressure arch breaks down and the pillars become subjected to the full overburden load. At some point, when the vertical stresses cannot be effectively transferred to the edges of the workings, the pillars may fail, leading to massive (i.e., large, contiguous areas) roof falls and possible caving and void propagation toward the surface (see Figure 4.3). These conditions are believed to be present to various degrees throughout the study area.

Several physical and mechanical factors may influence mine roof failure and resulting subsidence in the study area. Upward migration of the void initially begins with failure of the immediate mine roof, which is typically a function of the width and length of the opening and the strength and thickness of the rock mass forming the immediate roof. The void may propagate rapidly to the surface or take several decades to propagate to the surface and cause subsidence. The propagation rate and distance above the mine opening to which the void ultimately propagates depends primarily on the depth of the opening and the characteristics of the overlying rock.

4.4 FACTORS INFLUENCING MINE ROOF STABILITY

4.4.1 Strength of Roof Rock

The strength of the rock that forms the immediate mine roof is a primary factor in mine roof stability. The strength of the mine roof is also generally proportional to the thickness of the rock layer comprising the roof. Most of the mining in the study area took place in the Boone Formation, which is predominantly composed of bedded chert, a relatively high strength siliceous rock. The Boone Formation is in turn overlain by the Quapaw and Hindsville Limestones that in most locations are not as strong as the Boone chert, but stronger than the composite overlying shales, interbedded sandstones, and alluvium.

In some locations mining extended upward into the limestones above the Boone Formation, and in some cases into the overlying sandstone and shale. Mine roof rock in these areas would thus be much weaker and such areas would be more prone to roof failure and subsidence than areas where mining was entirely confined to the Boone Formation.

Roof rock strength can also be significantly degraded by the degree and orientation of natural fractures and joints present in the rock. Details regarding the geology and degree of fracturing in the study area are not available except for one or two mining leases. It is believed, however, that the degree of fracturing in rocks in the study area is greatest in areas of past tectonic deformation, such as within and near the Miami Trough and near other major structural features such as faults.

4.4.2 Pillar Shaving and Removal

Secondary mining was practiced throughout the Picher Mining Field during the major mining periods (see Sections 1 and 2) as well as toward the end of mining in 1970. However, the largely unregulated shaving and removal of pillars that occurred toward the end of the mining era likely increased the subsidence potential above that present following the primary and more controlled secondary mining done by the mining companies.

In general, pillar shaving reduces the load-bearing area of the pillars and increases pillar stresses, potentially leading to pillar yield and/or failure. Transfer of stresses from yielding or failed pillars to adjacent pillars results in an overall decrease in opening stability. At some point in this process stope width would become a limiting factor with regard to stope roof stability, and ultimately caving and subsidence potential. Complete removal of pillars results in large unsupported spans and leads to the modes of failure described above.

4.4.3 Effects of Blasting

Blasting, especially over-blasting, produces fractures which weaken the outer portions of a pillar and consequently reduce the effective area through which overburden loads can be supported. This reduction in load carrying area results in increased pillar stresses in the central, undamaged portion of the pillar. Thus, pillars subjected to blasting damage, either as a result of original mining or subsequent shaving, may actually yield and fail well before what would otherwise be expected based on the size of the pillar.

Similarly, blasting to excavate a shaft can also have a detrimental effect on the strength of rock surrounding the shaft. Thus, locations where mine shafts penetrate a mine roof may also be local areas of weakened mine roof rock and potential roof instability.

4.4.4 Hydrogeologic Effects

The inundation of the mines following the end of mining has likely had a stabilizing effect on the abandoned mine workings. Hydraulic pressure from the groundwater within the mines provides a buoyant force that helps to support the overburden and reduce the vertical stresses on the roof and remaining mine pillars. The abandoned mines in the study area are currently flooded and submerged below more than 75 feet of water. The groundwater level is at about 800 feet elevation and fluctuates from 790 to 805 feet as measured in the Blue Goose mine shaft (EPA, 1994 - Tar Creek Five Year Review). Significantly lowering groundwater levels below these elevations, either due to climatic conditions or human activities, may increase the potential for mine collapse and subsequent subsidence through several processes, as briefly discussed below.

Increased Pillar Stress: Significant lowering of water levels in the mines would reduce the buoyant forces acting on the mine roof and effectively increase the vertical load on the roof pillars, potentially leading to increased instability.

Volume Change: Lowering of the water table would likely decrease the moisture content of the overlying shale. Reducing the moisture content of shale typically causes shrinkage (volume reduction), which could lead to tensile stresses, cracking, and reduction of lateral confinement of the shale rocks overlying the mine workings. This shrinkage and cracking would likely reduce the effective strength of the shale overburden and increase the load on the non-shale mine roof rock.

Slaking: In some shales and volcanic rocks, radical deterioration in the rock quality and strength properties can occur after a rock surface is exposed to the air, either due to excavation or dewatering. Repeated cycles of wetting and drying can lead to significant strength reductions of shaft and existing subsidence walls, which could contribute to shaft related collapse and enlargement of existing subsidence features. Lowering of groundwater levels below the upper levels of mining in the study area is unlikely, but could also lead to significant strength reductions of the mine roof where the roof is located in or near the overlying shale. Strength reduction of limestone or chert owing to exposure to air would not be expected.

As discussed above, lowering of the groundwater table in the Picher Mining Field may accelerate the incidence of subsidence throughout the project area. It has been observed that the incidence of shaft related failures increases (Keheley, 2005, personal communication) during periods of drought. This observation is also consistent with experience that natural sinkholes often occur in karstic terrain during periods of drought and groundwater decline.

4.4.5 Seismicity

Section 3 summarizes the probability of significant seismic events in the study area. Projected Seismicity is low and any related effects are expected to be minimal. In addition, the impact of seismic effects on underground excavations is typically less pronounced than at the ground surface. Seismicity is therefore not expected to be a significant factor contributing to future subsidence potential in the Picher Mining Field.

4.4.6 Anthropogenic Effects

Surface land uses will usually have little effect on underground roof or pillar stability. However, the large mine waste or chat piles that remain in the area will continue to contribute to pillar loading, especially when underlain by laterally extensive mine workings. Deep surface excavations could also have undesirable consequences on subsidence potential if they were to disturb remnant pressure arches and induce local mine roof failure and caving.

Loading and vibrations from vehicles traveling on overlying roads are thought to have minimal effect on subsidence potential. However, the potential effects on subsidence of dynamic loading from vibrations caused by heavy truck traffic on irregular or uneven road surfaces are not well known and could be of concern in areas where roadways pass over shallow mine workings

4.4.7 Catastrophic Pillar Failure (Domino Effect)

The role that pillars play in determining the overall stability in a given stope or mining area was discussed in Section 4.4.2. In the Picher Mining Field, a stope may be defined as a room-and-pillar area surrounded by solid ground, or as an area supported by small or widely spaced pillars that is surrounded by solid ground and/or larger or more closely spaced pillars. Defining such areas on mine maps is inherently subjective.

In the case of a room and pillar area surrounded by solid ground, failure of individual pillars would transfer load to adjacent pillars that may subsequently fail, leading to increased load and pillar failure throughout the stope. At some point, the roof may fail and cave to the surface, relieving the load on the remaining pillars or solid rock and effectively arresting the subsidence process.

In the case of an area supported by slender pillars that are surrounded by solid ground and larger pillars, failure of the small pillars would cause loads to be transferred to the larger adjacent pillars, which may be more capable of supporting the transferred load. As in the previous case, roof failure and caving may occur and relieve loads on the remaining pillars. This is believed to be the case in the Domado mine, where mine maps indicate that several small, slender pillars were present beneath the area of a large stope that ultimately collapsed. Larger, remnant pillars bound the northern and eastern edges of this collapsed area.

The potential for future pillar collapse and the domino effect of adjacent pillar collapses can be evaluated using various numerical and mine stability analysis methods. Such methods, however, require some detailed information on the size, distribution, and condition of the pillars. One of the major limitations to the subsidence analysis in the Picher Mining Field is the lack of confirmed information on the presence and condition of pillars. It is believed that many pillars shown on existing mine maps may have been either removed or shaved.

4.5 FACTORS INFLUENCING SUBSIDENCE

4.5.1 Opening Dimensions

In longwall coal mining the width-to-depth ratio of the mine opening is commonly used in combination with the extracted seam thickness to determine the potential magnitude of trough type subsidence. The opening width-to-depth ratio has also been used in hard rock mining as an indicator of subsidence potential over vertically extensive stopes.

In general, stope width provides an indication of the potential for mine roof failure, and stope height and depth provide a measure of the potential for a mine roof failure and subsequent caving to reach the ground surface. In essence, wide and high openings at relatively shallow depths below the surface are more likely to result in subsidence than narrow and/or low openings at greater depths.

4.5.2 Extraction Ratio

Extraction ratio is a measure of the volume or areal extent of ore extracted in a given stope relative to the premined volume or area of the stope. For mine openings of rectangular cross section, the volume extraction ratio and the areal extraction ratio are the same. An areal extraction ratio of 1.0 (100%) indicates that all the ore was extracted and no pillars were left. An extraction ratio of 0.75 (75%) indicates that 25% of the mined area was left as pillars. In general, measurements from mine maps in the study area indicate that areal extraction ratios in the Picher Mining Field exceed 0.90 (90%), with relatively small pillars located throughout a maze of interconnected workings. Extraction ratio, however, is not a reliable single measure of either roof failure or subsidence potential, in that it is independent of the geometric factors (e.g., stope width, length, height and depth) that contribute to collapse and subsidence. Nevertheless, once the critical width of a stope has been reached, the presence or absence of pillars will determine the stability of the immediate roof, and a lower extraction ratio will promote opening stability.

4.5.3 Process of Bulking and Bulking Factors

The depth to and height of an underground opening, in conjunction with the bulking characteristics of the overlying rock mass, will determine whether a void initiated by mine roof failure will eventually propagate to the surface. In an abandoned mine, roof failure and subsequent upward caving of the overlying rock leads to the accumulation of a growing pile of broken, unconsolidated rock on the mine floor. As the caving or chimneying progresses upward the pile grows, but because the broken rock occupies a larger volume than the intact rock the height of the pile on the mine floor grows faster than the thickness of mine roof that has failed. As the caving or chimneying process continues, the void between the failing roof and rock pile will either fill and the process will be arrested, or it will continue until it breaks through to the surface as a chimney or plug subsidence.

The measure of the volume of broken rock to intact rock is called the "bulking factor", and it varies for different types of rocks. If the bulking factor for the rock is 1.4, failure of 10 feet of mine roof will result in approximately a 14-foot high pile of broken rock (some spreading of the caved rock laterally into the mine opening will likely occur). Bulking factors of rock typically range between about 1.3 and 1.5 (Bell and Stacy, 1992; Whittaker and Reddish, 1993). Weaker rocks such as shales have bulking factors on the low end of the range, and the stronger, more brittle rocks are on the higher end of the range.

In a study of subsidence above abandoned coal mines, the Colorado Mined Land Reclamation Division (CMLRD) has developed an equation for the probability of subsidence based on mine depth and void height (CMLRD, 1986). For a probability of 1.0 of subsidence, the ratio of depth to mine floor to void height was 6.2 or less. This ratio indicates a bulking factor of about 1.2 for the coal measure rocks overlying the mine workings. Similarly, the Ohio Department of Transportation (ODOT) has developed a detailed site evaluation procedure for evaluating subsidence potential along transportation corridors located above abandoned coal mines (ODOT, 1998). The ODOT procedure uses the ratio of minimum overburden thickness to maximum mined interval thickness as an indicator of chimney subsidence potential. A ratio of overburden thickness to mined interval thickness of 5.0 is used by ODOT to represent the highest likelihood of subsidence, and corresponds to a bulking factor of 1.2.

The bulking factor of 1.2 based on the above CMLRD and ODOT experience is for coal measure rocks that are predominantly shales and sandstones. However, different geologic materials will have different bulking factors, and it is possible that areas of the Picher Mining Field that contain a significant thickness of limestone bedrock in the immediate roof and overlying horizon will have a higher bulking factor (i.e., lower subsidence potential) than areas that are overlain by shale alone.

4.6 SUBSIDENCE ANALYSIS METHODS

Various methods are available and have been used in the past to evaluate mine stability and subsidence potential. Most of the methods are appropriate to site-specific studies and require relatively detailed geologic and rock property information to be effectively utilized. As such, they are not readily applicable to evaluating subsidence potential over large areas such as required in this evaluation. They may be applicable, however, in later, more detailed studies and geotechnical evaluations of specific locations identified as high risk for future subsidence. A brief summary of some of these evaluation methods used in non-coal mines is presented below.

4.6.1 Crown Pillar Stability Analysis in Hard Rock Mines

The layer of rock that separates the roof of the shallowest underground opening in a hard rock mine from the ground surface is commonly referred to as a "crown pillar." Methods for analyzing crown pillar stability, and hence the potential for subsidence, have been developed using Rock Mass Quality (Barton, 1974) and Rock Mass Rating (Bieniawski, 1974) systems that were originally developed for and subject to more widespread use for rock tunnel stability analyses. Along with RMR, the Mining Rock Mass Rating and Modified Stability Graph methods have been developed and tailored for use in stope stability analyses. These methods, however, are intended for use in site-specific evaluations and require the use of detailed geologic and rock property data and information that is not currently available for the study area.

4.6.2 Plate and Beam Analyses

Roof stability analyses can be conducted assuming that the mine roof can be modeled as a plate or a beam. These analyses utilize the stope width and stope length (plate analysis) or stope width (beam analysis), the thickness of the roof rock, and the mechanical properties of the roof rock (e.g., tensile and shear strength). The maximum stress in the plate or beam is inversely proportional to the beam or plate thickness. In roof stability analysis the thickness of the roof rock is substituted for plate or beam thickness (Adler and Sun, 1976)

4.6.3 Rock Mass Rating, Mathews Stability Graph Methods for Stope Stability Analyses

As with crown pillar analysis, standard stope stability analyses have utilized Rock Mass Rating, Mining Rock Mass Rating, Hangingwall Stability Rating, and most recently the Mathews Stability Graph (MSG) for stope design. In these cases, designers seek to maximize the dimensions of an open stope prior to mining. These methods require the use of detailed geotechnical data typically collected during mine exploration. The detailed data required for reliable use of these methods is not available for mines in the Picher Mining Field. Nevertheless, a general discussion of one of the most recently developed stope stability methods illustrates the parameters that are important to determining stope roof stability.

The MSG method, as reported by Mawdesley (2000), relates the Mathews Stability Number (N), a measure of the rock mass properties, stress, and opening orientation, to the hydraulic radius of the stope (area of the stope roof divided by the perimeter of the stope roof). The hydraulic radius is a convenient one-parameter measure of the geometry of the underground stope. In this type of analysis the hydraulic radius is used as a geometric measure of stope instability.

4.6.4 Numerical Methods

Subsidence may be evaluated using numerical methods, such as finite element and finite difference techniques where there is sufficient and reliable mine geometry, geologic, and rock property data to provide required input into the numeric models. Several types of software packages are commercially available, including Itasca's FLAC model. The FLAC model, as well as others, has been widely used in the mining industry for mine design and to evaluate mine stability and subsidence.

Numerical modeling is not considered to be applicable to the current study due to the lack of accurate, mine-specific rock property data. However, it may be applicable to future, mine-specific subsidence evaluation in areas that have been identified as having a high likelihood of subsidence based on this study.

4.7 METHOD UTILIZED FOR THIS EVALUATION

Factors considered in the selection of an appropriate subsidence prediction tool for use in the Picher Mining Field are the characteristics of existing ground-failure case studies; the data and information regarding ground conditions throughout the study area that would be available for use in the analysis; the goals and use of the analysis tool that was developed; and the available technology, models, and computer software.

The lateral extent of mines in the study area required the selection and use of a systematic, computer-based subsidence potential evaluation methodology. The following criteria were thought to be essential in accomplishing the project's goals:

- Ability to adapt the methodology for use with Mine Planning Software (MPS) or a Geographical Information System (GIS) so that systematic evaluation could be performed for the entire study area.
- Ability to predict the potential for chimney, or plug type subsidence to occur.
- Ability to estimate the potential magnitude of vertical subsidence if mine roof failure was to occur.

Consideration of the above factors and goals dictated that an empirical or semi-empirical approach be used for predicting the potential for subsidence in the study area. In such an approach, data associated with prior collapses are collected, characterized, and catalogued, and then subjected to parametric analysis to determine the contribution and importance of each parameter relative to ground failure. The rationale and methodology are then developed for the application of this information in forward analysis models to predict the location and likelihood of future subsidence. Such an approach was utilized in this subsidence hazard evaluation.

4.8 SECTION 4 REFERENCES

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Insert Figure 4.1, *Illustration of Pressure Arch and Yield Pillar Concepts*

Insert Figure 4.2, *Illustration of Non-shaft Related Collapse*

Insert Figure 4.3, *Various Stages of Shaft Related Collapse*

5 Picher Mining Field Subsidence Evaluation Process

5. PICHER MINING FIELD SUBSIDENCE EVALUATION PROCESS

The large size of the study area and quantity of available data necessitated the adoption of a systematic process of data collection and assimilation. Data requirements were dictated by the selected predictive tools and by the need to prepare and provide a comprehensive database of underground mines, mine shafts, and existing subsidence features.

5.1 DATA ACQUISITION AND PROCESSING

The Oklahoma Conservation Commission (OCC) assembled mine maps and supporting data for use in the current study. Maps, drill logs and aerial photographs were obtained from numerous sources (Missouri Southern State University, the Picher Mining Museum, personal collections of Subsidence Evaluation Team members, the Quapaw Tribe archives in Tulsa), including in-house OCC resources. Selected resources were indexed and scanned into electronic format, including:

- 264 geology and mining related articles and documents pertaining to the Picher Mining Field scanned by the U.S. Army Corps of Engineers.
- 173 mine maps scanned from the U.S. Department of Interior Bureau of Land Management (BLM) archives for the Picher Mining Field.
- 397 documents scanned from the BLM archives for the Picher Mining Field.
- 348 mine maps scanned from the Picher Mining Museum in Picher, Oklahoma.
- Over 500 maps scanned from Missouri Southern State University's archives.

The OCC placed the most complete set of mine maps for mines located in the study area on a dedicated FTP site. These files were subsequently downloaded and processed for inclusion in the GIS model.

5.1.1 Mine Map Processing

Mine map images provided by OCC were digitized to create Mine Vector Graphics (MVGs). The MVG is a vector representation of a scanned mine map including separate matching Digital Elevation Models (DEMs) to represent elevations of separate mine workings, georeferenced to the Oklahoma State Plane North NAD 83. The process involved:

1. Production of each MVG began with the scanning of a paper copy of the selected 40-acre map on a high-resolution scanner. Scanning resolutions ranged from 300 to 600 dpi with the output file running between 100 to 300 Mb. Some were scanned as bi-tonal and some as true color.

2. Images not in a bi-tonal form were converted to index color then to bi-tonal. Cleanup of images occurred at this phase. Converting images to bi-tonal was necessary to allow our software (AutoCAD Land Development Desktop) to assist in the digitization process.

3. A reference section grid was prepared by OCC in the Oklahoma State Plane North NAD 83. Reference section lines were based on road intersections obtained from aerial photography. This was done in an effort to re-create the original section grid that predates the NAD 1927 datum.

4. Each map was then placed on this grid and scaled in the X and Y direction but not skewed or twisted (printed maps tend to shrink or expand across the grain of the medium). This created a continuous coverage of images across the study area. Most maps were fairly seamless on the overlaps. However, on some of the map overlaps there is a survey "bust" of up to 6 feet (Section 17, T29N, R23E), but typical discrepancies range from 0 to 3 feet. If two maps conflicted on remaining pillars or excavation, the maximum excavation was assumed.

5. The main image drawing was then split up into 40-acre maps for digitization by several employees using AutoCAD Raster Design. A set of closed polylines was produced for each 40-acre mine lease. In a separate drawing, the elevations of the mine workings were created as 3-D breaklines and points. Great attention was paid to the floor breaklines, however, in some cases they were assumed. These lines and points were added to a DTM (Digital Terrain Model), created one section at a time.

6. The DTMs were exported as Trianglulated Irregular Networks (TINs) in a DXF file format. These TINs and closed polyline sets for each 40-acre mine lease were handed off to another Subsidence Evaluation Team member for analysis in ArcGIS.

7. TINs and closed polyline sets for each 40-acre mine lease were also imported into GEMCOM. GEMCOM is a 3-D mine planning and solids modeling program. This was done to provide the ability to cut cross-sections and compute volumes. The process in GEMCOM was as follows:

   - TINs were imported into GEMCOM as surfaces one layer at a time.
   - Polyline sets were converted to ASCII files. One file for each level in each mine.
   - One level of polylines from each mine map was then imported into GEMCOM.
   - Polylines were set at zero elevation.
   - Polylines for that level were then extruded up 900 feet and named.
   - These new solids were then clipped on the top and the bottom with the TIN surfaces.
   - Once the solids processing was complete, cross–sections were cut every 200 feet on the Northing and Easting in a grid.
   - Sections were then exported back to AutoCAD for page setup and plotting.

8. The positional accuracy of the mine workings was determined as follows:

   - Horizontal positional accuracy: While the datum of the published map was retained to be consistent with the original 1929 section corners, the image was cast on the Oklahoma State Plane North NAD83. The placed section corners may be inconsistent with current section corners shown in the source map image.
   - Vertical positional accuracy: The vertical datum for some of the mine map images was set prior to 1922; others have been updated with the NAD29 datum. The vertical elevations were taken directly from the source maps and were not adjusted.

5.1.2 Borehole Data Processing

The work scope of the Borehole Subgroup included the selection and extraction of geologic borehole data from historic exploration boreholes that were drilled in advance of mining. A large number (greater than 40,000) of exploratory borehole logs were made available for the study. The guideline provided to the subgroup was to geolocate and interpret ten boreholes per 40-acre mine lease, for a total of 1,340 boreholes in the study area. Data were selected based on a physical examination of the mine maps to provide spatial coverage for each 40-acre parcel. The following protocol was adopted to identify geologic contacts on the boring logs:

- The first occurrence of soapstone or shale was labeled as the “top of shale.” Soil above that contact was labeled “alluvium.”
- The first occurrence of limestone was labeled “top of Chester,” unless flint or chert was mentioned.
- The first occurrence of flint or chert was labeled as “top of Boone.”

Each borehole log was examined to ensure that it contained sufficient data to adequately populate the spreadsheet. Those boreholes with geological designations that better fit the selection criteria were selected in preference to those that did not contain the requisite data or required interpretation. Just over 3,800 boreholes were eventually processed and provided to the Subsidence Evaluation Team, representing a three-fold increase over the original goal. Borehole locations were determined from geo-referenced maps (see Appendix B).

5.1.3 Aerial Photography

Aerial photography used in the identification of subsided areas and residential and transportation areas was acquired from the EPA. Photography was performed in 2004 at a resolution of 6 inches and was true color. The photographic images were geo-referenced in State Plane coordinates and used for a background on final exhibits for this report.

5.1.4 Data Quality Assurance/Quality Control

5.1.4.1 Mine Map Data

SubTerra digitized historic mine maps into an electronic format using maps that had been scanned as part of the data acquisition process. The vector data files were then input into the GIS model by MWH, and the spatial representations of the mine workings were checked to ensure accuracy. As a subsequent check on the mine map data the U.S. Army Corps compared spot elevations from the mine maps to the appropriate roof or floor raster information from the GIS database, and SubTerra used cross-sections developed from the 3-D model to evaluate the positional accuracy of plan and elevation data.

5.1.4.2 Borehole Data

The USGS interpreted exploration borehole logs and inspected data for outliers and anomalous values. Stratigraphic contacts selected were based upon historical criteria and were used throughout the area. Borehole logs were selected by spatial distribution and ease of interpretation. Generally, the lease used the same drillers and the language describing the cuttings was consistent. MWH checked for data completeness and consistency during incorporation of this information into the GIS model. This review of the borehole data included a review for consistency and quality. During this quality review, six of the borehole records contained clearly incorrect data. The incorrect data were noticeable due to:

- Ground surface elevations outside of the known range of ground surface elevations within the study area.
- Depths to the top of shale (part of the alluvium/shale unit) that were deeper than the top of the Chester Formation, which is stratigraphically lower than the alluvium/shale unit.

These boreholes were removed from the dataset used in the analysis. Other incorrect data may be present that are not noticeable without detailed knowledge of the geology at each location, which is beyond the scope of this study. Additional information is available from the borehole data set for areas not included in this study.

5.2 CONCEPTUAL SITE MODEL

Data acquired and generated for the Picher Mining Field subsidence evaluation were assembled and were input to a GIS database that was used to develop a Conceptual Site Model. This Conceptual Site Model is a representation of geologic and mine-specific information that allows the analysis of these features as they relate to mine subsidence. The development of the Conceptual Site Model from assembled data is described in the following sections.

5.2.1 Borehole Data

The study area consists of three geologic units that are of concern for the analysis of subsidence in the Picher area. These units are, from youngest to oldest: alluvium/shale, the limestone, and the Boone Formation. A detailed description of the geology of the Picher Mining Field is included in Section 3. The USGS provided a tabular list of over 3,800 selected boreholes within the study area that were drilled for exploration purposes prior to mining and represent pre-mining geologic conditions.

The borehole data table indicates the elevation of the ground surface, and the depth to the top of the shale, limestone, and Boone chert at each borehole (see Appendix B). These data were used to calculate the thickness of each unit, as discussed in more detail in the following section.

5.2.2 Thickness of Geologic Units

The thickness of each of the geologic units was derived from the borehole records discussed in Section 5.2.1, above. The first step in the process of estimating unit thickness was to calculate the thickness of the alluvium/shale and Chester at each borehole location. If the unit was absent at any one location, the thickness at that location was set to zero. This was accomplished outside of the GIS model using spreadsheet software. The boreholes were then represented in the GIS model as points using Easting(s) and Northing(s) obtained from mine plans, and the collar elevation and associated geologic information data obtained from each borehole record. These points and the associated unit thickness were then used to generate rasters, or a grid of uniformly sized cells, representing the thickness of each geologic unit for the complete study area. All raster interpolations of the thicknesses were produced using the natural neighbors interpolation method. The natural neighbors interpolation method handles large amounts of data points better than other methods and is well suited for continuous surfaces with abrupt changes, such as geologic contacts. The interpolation extended as far as the boundary formed by the perimeter of the boreholes, and no extrapolation was conducted outside of the area of boreholes. The interpolated area includes all of the known mine workings in the study area, as shown on the historic mine maps.

Mining occurred primarily within the Boone Formation, but did extend up into the Chester in some limited areas. Nowhere did mining extend below the bottom of the Boone Formation. In order to calculate the thickness of the Boone Formation above the stope, a raster of the top of the Boone Formation elevations was first generated over the whole study area. The Boone Formation thickness above the stope was then calculated (only for areas where mine workings are present) by subtracting the mine roof elevations from the top of the Boone Formation elevations to generate the raster for Boone thickness above the stope. Where mining extended up into the Chester Formation, the Boone Formation thickness above the stope was set to zero.

5.2.3 Geologic Structure

In addition to reviewing the borehole records for accuracy, a comparison was also made to known geologic structures in the area. Major geologic structures were digitized from McKnight and Fisher (1970), and added to the GIS. These structures consisted of the following:

- Miami Trough
- Bendalari Monocline
- Rialto Basin

These structures were overlain on the unit thickness maps, as well as structure contour maps, of the alluvium/shale unit, Chester and the Boone Formation (pre-mining). The complexities seen in the geologic maps (e.g., rapid changes in elevation or thickness) were compared to the locations of these geologic structures. This evaluation revealed that, for the most part, the areas of greatest complexity in the geologic units correspond to the locations of the major geologic structures. Some areas of greater complexity of the geologic units occurred in areas away from the major structures, and likely reflect smaller geologic structures not mapped.

5.2.4 Surface Topography

Surface elevation information used in the GIS model was developed from contouring borehole collar elevations included on the exploration borehole logs discussed above. More recent LIDAR survey data coordinated by the USGS was available but was not used. Use of mapping based on the historic borehole data allows development of a topographic surface representative of conditions prior to placement of chat on the surface and an accurate representation of the elevations of pre-mining formation contacts. Using the recent LIDAR mapping would have misrepresented natural geologic units in depth-to-stope calculations.

5.2.5 Mine Workings

The location of historical mine workings was documented on paper mine maps obtained from various sources including the OCC, the Picher Mining Museum, Missouri Southern State University and personal collections. These maps were developed through the period of primary mining and include detailed boundaries of the mine workings, interior support pillars, and point elevations on the roofs and floors for over 134 separate quarter-quarter sections of mines. Tabular, vector-image and grid data necessary to perform the analyses discussed in the following sections were loaded into the GIS model.

5.2.6 Data Processing

This section of the report describes the approach to building the GIS model, and how the GIS model was used to evaluate the potential subsidence and probability of subsidence in the study area. The GIS model created for this subsidence investigation is also intended to serve as a resource and basis for future studies and management programs in the Picher Mining Field.

5.2.6.1 3-D Geometry of the Mine Workings

The 3-D geometry of the mine workings was digitized from the historical paper mine maps. These maps were developed through the period of primary mining and included detailed boundaries of the mine workings and pillars and point elevations of the roofs and floors at periodic locations throughout the workings. These maps typically represented quarter-quarter sections (40-acre parcels) that corresponded to the historic mine lease boundaries generally drawn at a scale of one-inch to fifty feet (see Table A.1 in Appendix A). Due to processes such as roof falls, collapse, and later pillar shaving or pillar mining, the current roof and floor heights and boundary locations may be different from those presented on the mine maps.

The mine maps were first digitized in AutoCAD as TINs. A TIN is a vector data structure that partitions geographic space into contiguous, non-overlapping triangles of varying shapes and sizes. The vertices or corners of each triangle are sample data points with an x, y, and z value for each point (e.g., the point elevations on the historic mine maps indicating location and elevation). TINs are a numeric method specifically used to store and display surface models. A separate TIN was generated for each roof and each floor of each ore horizon (mining layer). The TINs were then imported into the GIS model for further analysis.

Within the GIS, the TINs were converted to rasters in order to conduct raster math for the subsidence analyses, as described in Sections 6.3 and 6.4. A raster is a spatial data model that defines space as an array of equally sized cells arranged in rows and columns. Each cell contains an attribute value and location coordinates. Unlike a vector structure, which stores coordinates explicitly, raster coordinates are contained in the ordering of the matrix. The attribute of the grid cells in the mine working rasters is elevation. The mine workings, surface topography, and geologic rasters were developed on a 10-foot-square grid spacing.

5.2.6.2 Raster Math

The analyses described in Sections 6.2 and 6.4 of this document were accomplished in the GIS model using a raster function called raster math, which allows the performance of mathematical calculations using mapping data from the GIS model. Inputs to the raster math equation(s) can be rasters, vector files, tables, constants, and numbers. Raster math was used to calculate the potential maximum subsidence and the subsidence probability using the equations described in Sections 6.3 and 6.4.

5.3 SECTION 5 REFERENCES

McKnight, E. T.; and Fischer, R. P., 1970, Geology and ore deposits of the Picher field, Oklahoma and Kansas: U.S. Geological Survey Professional Paper 588, p. 165.

6 Evaluation Tools and Methods

Early mining photo showing ore cans being used to move the mined ore to the shaft opening to be lifted to the surface.

6. EVALUATION TOOLS AND METHODS

The Subsidence Evaluation Team identified three primary types of information that would be useful to land managers and convey the information on the extent, probability, and magnitude of mine subsidence that could affect the study area. These three types of information are:

- Mapping that indicates the location of mine workings and mine shafts.
- Mapping that indicates the potential maximum subsidence from mine workings, and,
- An analytical tool to evaluate the probability of subsidence for prioritizing sites.

The following portions of Section 6 discuss the methods that the Subsidence Evaluation Team used to develop this information within the Picher Mining Field.

6.1 SUBSIDENCE FACTOR IDENTIFICATION

Information available for the Picher Mining Field related to mine subsidence is generally limited to the mine mapping and geologic information discussed in previous sections of this report. The lack of any detailed rock mechanics data for the study area and the need to use available information in any analysis limited subsidence-factor identification to the approach and factors described in the following subsections.

6.1.1 Purpose of Back-Analysis

The purpose of the back-analysis of large existing subsidence features resulting from mine collapse was to identify those factors or combinations of factors that are common to the existing subsidence features. Variables associated with both collapse and non-collapse subsidence case studies were tabulated and analyzed statistically to determine those factors and/or combinations of factors that are associated with large subsidence features. These critical factors were then used to evaluate the probability of similar future subsidence events in the study area that were not part of the case studies.

6.1.2 Approach

Early in the planning process, the Subsidence Evaluation Team determined that the empirical back-analysis approach outlined above offered the only viable method to determine the probability of subsidence in the study area. The inventory of mine collapse features compiled by Luza (1986) was used to select a sample of typical collapse features throughout the Picher Mining Field. The types of features selected for the back-analysis were typically the large, crater-like subsidence features because such subsidence represents the greatest danger to public safety. These large subsidence features are also readily identifiable as resulting from underground mine collapses, whereas smaller subsidence features may be related to shaft failures or natural processes such as karst formation.

Luza (1986) distinguishes two types of subsidence features in the Picher Mining Field: shaft related and non-shaft related collapses (see Sections 2 and 4). Shaft related collapses typically result from the failure of wooden cribbing in the upper portions of a shaft where it penetrates the shale, sandstone, and near-surface soils. These weaker materials then collapse into the shaft, forming a circular collapse feature that typically enlarges with time due to erosion and further deterioration of the shaft opening. Some of these shaft failures can become quite large over time (Luza, 1986). The second type of subsidence identified by Luza (1986) results directly from the collapse of underground mine workings, and is referred to as non-shaft related collapse.

Most of the subsidence features in the Picher Mining Field are shaft related collapses (Luza, 1986). Although shaft related collapses represent a significant hazard in the Picher area, the back-analysis focused only on non-shaft related collapses. This is because the mechanisms involved in the two different types of subsidence are entirely different. Also, the extensive inventory of mine shaft locations in the Picher Mining Field (Luza, 1986; Keheley and Pritchard in Oklahoma Governor Frank Keating's Tar Creek Superfund Task Force Final Report, 2000) provides information on the locations of these potential hazards, and the area of potential hazard from a shaft collapse can be easily defined. Locations of non-shaft collapse features, on the other hand, are much more difficult to identify and are dependent on a wider range of factors than shaft related collapses. Thus, the back-analysis was concerned only with non-shaft related collapses. However, as will be discussed later, the presence or absence of shafts was a factor considered in the back-analysis of the non-shaft related collapse.

In order to determine the factors that contribute most to large subsidence features in the Picher Mining Field, it was necessary to also include areas of no subsidence in the statistical analysis. Therefore, areas of mine workings similar to and near those that produced subsidence features were also selected for inclusion in the case studies.

During initial planning meetings to develop the strategy for conducting the hazard assessment, the Subsidence Evaluation Team collectively developed an initial list of variables that were thought possibly to contribute to mine collapse and ultimately, subsidence. A subgroup of the Subsidence Evaluation Team, the Back-Analysis Subgroup, was later formed to refine this list of variables and to select the case study areas. The Back-Analysis Subgroup also interpreted mine maps, drill logs, and other sources of information in order to determine and tabulate the values for the selected variables for each case study.

6.1.2.1 Selected Mine Subsidence Variables

The Back-Analysis Subgroup used existing mining and rock mechanics literature, and the personal experience of members, to select a set of variables that were suspected of contributing in some way to the occurrence of subsidence. These variables were included in a statistical analysis that ultimately led to the identification of a selected set of variables that are highly correlated with subsidence. A brief explanation of each variable and why it was considered important in the back-analysis is provided. Some of the variables have numeric values, while others have simple “yes” or “no” values, depending on the presence or absence of a characteristic.

Number of mine levels present: Intuitively, the likelihood of mine collapse would be expected to increase where multiple-level mining took place. Not only is there greater opportunity for mine-roof failure with multiple levels due to reduced roof thickness at each level and the possibility of staggered pillars (as opposed to being stacked above one another), but the total volume of material removed by mining would be greater than if only single-level mining occurred, thus increasing the probability of subsidence should collapse of the underground workings occur.

Number of shafts within the stope or collapse area: Although back-analysis focused only on non-shaft related collapses, the presence of shafts within a specific stope or mining area was suspected to contribute to weakening of the mine roof. Thus, the presence of shafts within a stope area could possibly be a factor in the collapse of the underground workings, even if the upper portions of the shaft did not fail in the typical fashion.

Rock falls noted on maps: The presence of rock falls within the mine workings during mining is an indication of unfavorable mine-roof conditions. The team suspected that such locations are areas of possible future mine collapse and subsequent subsidence.

Pillars removed or trimmed: The trimming or removal of pillars results in the loss of support for the mine roof and increases the likelihood of collapse of the underground workings. Unfortunately, as discussed below, much of the pillar removal or trimming in the Picher Mining Field was done by gougers after the primary mining phase was completed; records of pillar removal are either absent or incomplete. The Back-Analysis Subgroup suspected that where pillars had been trimmed subsequent to the primary mining operations, there was a greater likelihood of instability due to inadequate support.

Chat pile over all or part of stope: The presence of chat piles on the surface above the mine workings results in additional load on the mine roof and pillars that was not considered by mining engineers when the mines were originally worked. The Back-Analysis Subgroup suspected that the existence of these chat piles could be a contributing factor to mine collapse.

Width of stope: The Back-Analysis Subgroup suspected that the greater the width of stope or mine opening, the greater the likelihood of roof failure and mine collapse.

Length of stope: Although it is generally recognized that the width, rather than the length, of a stope or mine opening is more likely to impact stability, the Back-Analysis Subgroup suspected longer openings afford an increased chance of encountering weaknesses in the mine roof, and thus could also be a contributing factor to mine collapse.

Maximum unsupported span: The greater the unsupported span within an underground opening, the greater the stress on the roof and pillars, and the more likely roof failure and mine collapse will occur.

Height of stope: Although the height of the stope is generally not a controlling factor in mine stability, it is a potential factor in mine subsidence. The greater the stope height relative to the thickness of overburden, the more likely that surface deformation (subsidence) will occur in the event the mine opening collapses.

Depth to top of stope: The closer the mine workings are to the surface, the more likely that mine collapse will result in subsidence. This is because there is less material above the mine opening to fail and bulk (expand) to fill the opening, thereby stopping upward stoping.

Interburden thickness between mine levels: Interburden is defined as the intact rock between adjacent mine levels. It is generally believed that thin interburden between two levels is more likely to fail than thick interburden. In addition, the Back-Analysis Subgroup suspected that failure of the interburden would effectively result in greater stope height, as two or more mining levels would combine into a single larger opening.

Areal extraction ratio: Areal extraction ratio is the ratio of the excavated area to the total area of a mine or stope. The greater the areal extraction ratio, the greater the amount of material removed by mining and, less material available to hold up the mine roof. In addition, higher removal rates result in more space to be filled by the overlying rubble as the mine collapses. For mine openings that are rectangular in cross-section, as is approximately the case for most mines in the Picher Mining Field, the areal extraction ratio is the same as the volume extraction ratio, which is defined as the ratio of the excavated-to-total volume of a mineral deposit or portion of a mine. Areal extraction ratio is easily determined from the mine maps. The Back-Analysis Subgroup suspected that a greater extraction ratio would result in greater likelihood of subsidence.

Ratio of height of stope to thickness of overburden: This is a calculated value from two of the previous variables. As noted above, the height of stope is not necessarily a critical factor in determining stope stability, but the height of stope relative to its depth below the surface is a factor in determining if mine collapse will propagate to the surface and produce a subsidence feature.

Thickness of Boone Formation above stope: The Boone Formation, in which most of the ore within the Picher Mining Field was mined, is a relatively strong and competent rock compared to the Chester and the shale units that overlie the Boone Formation. Therefore, the Back-Analysis Subgroup suspected that the thicker the overlying Boone Formation above the mine opening, the stronger the mine-roof and the more stable the opening.

Thickness of Chester above the stope: The Chester is a collection of less competent limestone and interbedded sandstones and shales, and is generally weaker than the underlying Boone Formation. The thickness of the Chester above the stope was therefore considered to be a possible factor in mine collapse and subsidence.

Thickness of alluvium and shale above the stope: The shale and alluvium that overlie the Chester are relatively weak and incompetent. As such they have little ability to provide roof support and may actually behave more as dead load on the underlying, more competent materials above the mine opening. Therefore, the Back-Analysis Subgroup suspected that the greater the thickness of shale and alluvium over the mine openings, the greater the potential instability of the openings.

Mapped tectonic/geologic features within or near the collapse or stope area: The presence of geologic features such as folds, faults, or fracturing may be a factor in mine collapse in that they represent weaknesses in the rocks that could degrade opening stability. Geologic factors considered in the back-analysis were the presence of faults, folds, or fracturing noted on mine maps and reports; proximity to the Miami Trough (within 1 mile); and the presence of karst structures. The Back-Analysis Subgroup believed that the presence of such features inside the footprint of a mine might lead to decreased strength and increased subsidence.

6.1.2.2 Selection of Case Studies

As noted earlier, the inventory of subsidence features in the Picher Mining Field (Luza, 1986) was used to select most of the back-analysis case studies. Several moderate to major subsidence features, identified by Luza (1986, Plate 2) as deeper than 30 feet and greater than 95 feet in diameter, were chosen for back-analysis. Criteria used to select the case studies included that 1) the subsidence feature be non-shaft related, 2) there be one or more exploratory drill holes in the area to provide subsurface geologic information, and 3) mine maps were available to define the extent and geometry of the mined area. For these reasons, not all of the moderate to major subsidence features inventoried by Luza (1986) could be included in the case studies. One small subsidence feature that occurred after the 1986 Luza inventory (case study #28, Scammon Hill Mine) was included in the case studies in order to incorporate a sampling of more recent collapses. Case study #7 (Ritz Mine) had also not been previously identified as a subsidence feature. During the course of this study, the question arose as to whether the pond at this location was the result of subsidence. Further field examination, including a depth profile of the pond by U.S. Army Corps staff, indicated that it likely was the result of mine collapse and was not a mill pond as previously thought. This location was therefore added to the back-analysis as a collapse case study.

The intent in selecting the back-analysis case studies was to produce a representative sampling of the larger, non-shaft related collapses over the entire Picher Mining Field so as to include a range of geologic conditions present within the field. Ultimately, a total of twelve subsidence features were selected for the back-analysis. In addition, a total of 17 non-subsidence examples were selected from the detailed mine maps. In most cases, the non-subsidence examples were taken from areas of the mine near where the subsidence occurred. In selecting the mine locations to represent non-subsidence cases, large stope areas similar to the collapsed stope were chosen.

The locations of the subsidence and non-subsidence case studies within the Picher Mining Field are shown in Figure 6.1. Figures Da through De in Appendix D show the location of the case studies at the scale of the individual mine lease in which they occur. These figures also show the width and length axes that were used to characterize the dimensions of the individual stopes, and thus provide some insight into the rationale used in deciding the stope boundaries.

A brief description of each case study is presented in Appendix D, along with a separate figure showing the detailed mine map in the area of the case study superimposed on 2004 aerial photography. The detailed figures also show the location and length of the axes used to define the stope dimensions as determined from interpretation of the detailed mine maps. Drill logs used in determining the thickness of geologic units at each site, and in some cases the elevations of the mine roof from assay data, are also included in Appendix D. Geologic contacts were picked from the drill logs using the same criteria applied in interpreting the logs to develop the Conceptual Site Model of the region, as described in Section 5.2.

6.1.3 Scope and Limitations

The empirical back-analysis approach used to develop the GIS screening criteria in this subsidence hazard assessment is intended to be applicable to the study area, and ultimately to the entire Picher Mining Field. Several factors may contribute to mine collapse and subsidence at any particular location, and the factors or combination of factors may not be the same in all cases. The back-analysis was therefore intended to develop a representative sample of variables possibly associated with mine collapse from the entire region, from which critical factors can be identified that may be used to estimate the probability of a major subsidence within the study area.

One of the major limitations to this approach is that all but one of the subsidence cases selected for back-analysis are major subsidence features, with horizontal dimensions on the order of 100 feet or more and vertical deformation of several tens of feet. As noted earlier, these larger features were selected because they represent the greatest potential threat to public safety, and almost certainly result from the collapse of large underground rooms, or stopes. Smaller subsidence features that occur in the Picher Mining Field are less easily identified and can result from processes other than mine collapse, such as shaft cribbing failure and dissolution of limestone resulting in karstic features. Trough subsidence, characterized by shallow subsidence over relatively large areas, was also not included in this analysis. Trough subsidence, while possibly present in the Picher Mining Field, is not easily identifiable and has not been well defined in the region. The screening criteria that result from the back-analysis are, therefore, only applicable in identifying potential areas of large surface deformation.

The reliability of the information used to quantify the variables for the back-analysis is also influenced by a number of factors, including the age and quality of the mine maps, the complexity of the maps, the subjectivity involved in selecting stope boundaries, and the complexities introduced by multiple-level mining. One of the biggest uncertainties arises from the question of pillar robbing and gouging activities that took place after the primary mining phase, and were thus not documented on the maps. Removal of pillars and/or enlargement of stopes by gouging would be a major contributing factor to mine collapse, but unfortunately, the areas where such activities occurred are poorly documented.

The mine maps used to determine stope dimensions were produced between 1945 and 1967. Most of the maps were produced between 1955 and 1965, and are thus considered relatively reliable with respect to final mine configurations. One or two possible case study sites were discarded early in the investigation because maps of those mines dated later than the 1930s could not be found.

The complexity of the mine maps also contributed to uncertainty in their interpretation. Complexity was mainly introduced where multiple-level mining was practiced. The various levels were portrayed on the maps with different types of lines, such as solid lines for the main level (generally called the "M" level) of mining, and variations of dashed and dotted lines for the upper and, in some cases, lower levels of mining. Where three or more levels of mining were present at the same location, it was often difficult to determine the final three-dimensional configuration of the workings. Also, mine floor and roof elevation data were often not displayed in sufficient quantity on the maps to allow the height of the openings to be determined. Oftentimes, two or more levels of mining combined to form one large stope. To make matters more difficult, it appeared that the convention of which type of line represented which level was not always consistent from mine lease to mine lease, and in some instances varied on the map of a single lease. This made it very difficult in some cases to determine the limits of individual stopes with a high degree of confidence.

In many cases, subjective judgment was also involved in selecting the stope boundaries. In some cases, the shape and lateral extent of stopes were obvious and could be well defined from the mine maps. In other cases, the irregular shape of the mined area, the varying density of pillars, and the lateral extent of mining in one or more directions suggest that a well-defined stope was not present. In such instances, the selection of dimensions to represent the stope was somewhat subjective. In several cases, the mine maps did not provide sufficient information on floor and roof elevations to reliably determine stope heights. In these cases, mine assay data from logs of nearby exploratory borings were used to infer stope heights. In several instances where both mine-map elevation data and borehole logs were available, a comparison between stope heights from the mine maps and those inferred from the assay data were in close agreement. The use of assay data to infer stope heights was thus considered to provide reasonable stope height estimates where mine map data were lacking.

The presence of multiple-level mining in some of the case study areas also presented a problem from the standpoint of the back-analysis. Where subsidence occurs over a single level of mining, it is obvious that the subsidence resulted from collapse of the underlying stope. Where multiple-level mining occurred, it was not apparent at which level the mine collapse may have initiated, and therefore unclear which stope dimensions and properties to include in the analysis. From a rock mechanics standpoint, however, the stability of the mine roof is primarily dependent on the width of the opening, the unsupported span, and rock strength properties, not on the height of the opening. Thus, the collapse of a lower level or levels to form a combined opening would not necessarily result in surface deformation. Subsidence will only occur if there is failure of the roof of the uppermost level, or crown pillar. Failure within the lower mine levels could ultimately result in failure of the crown pillar through effective widening of the underlying opening. However, because it is not possible to know where failure initiated in multiple-level collapses, it was assumed that mine collapse initiated in the highest level of mining. Therefore, the stope dimensions and properties tabulated in the back-analysis for multiple-level mining cases are for the uppermost stope.

Another source of uncertainty in the tabulated variables is in the interpretation of the exploratory drill logs to derive the geologic contacts, and thus determine the thickness of the overlying geologic units used in the back-analysis. Drillers, rather than trained geologists, compiled drill logs, and the common use of non-geologic terminology contributed some uncertainty in determining geologic contacts.

6.1.4 Tabulation of Back-Analysis Variables

All of the variables determined for the 12 subsidence features and 17 unsubsided case studies are presented in Tables 6.1A and 6.1B. Also included in the table is accessory information regarding the date or approximate date of the subsidence, the drill logs used to derive the geologic and stope data for each case study, the mine maps used to determine stope dimensions, the size of the surface collapse where applicable, and any additional comments. The case study number is presented in column 1, followed by the mining lease name in column 2. The case studies are organized by lease, and are designated as subsided or unsubsided cases in column 3.

Except as noted below, the data contained in Table 6.1A were subjected to multi-variant statistical analysis in order to identify those factors that are most commonly associated with the large surface collapses. These critical factors, once identified, were formulated into a logistic regression equation. Target areas within the study area having the potential for subsidence should complete collapse of the underground workings occur were identified using a GIS model. The logistic regression equation was then used to estimate the probability of subsidence of these target areas. Target areas where the critical factors are present are thus identified as areas of relatively high subsidence hazard.

It is noted that case study #28 (Scammon Hill Mine) was not included in the final statistical analysis to determine key subsidence factors. This particular case study is a small surface collapse compared to the other case studies; although the mine workings under the subsidence feature are relatively high, they are narrow and occur at greater depth than all but one of the other case studies. Because of the mine geometry and depth, this case study did not fit the statistical trend suggested by the other surface collapse cases. The presence of mine shafts near the subsidence feature and the existence of underground caves noted in descriptions of this mining area raised concerns that the subsidence might have been caused by processes other than mine collapse. The small size of the subsidence feature, and the uncertainty that it resulted from the same processes as the other collapse case studies, lead to the decision to exclude it from the statistical back-analysis. Although not included in the final statistical results, case study #28 has been retained in Tables 6.1A and 6.1B.

6.2 STATISTICAL ANALYSIS OF VARIABLES AND IDENTIFICATION OF CRITICAL FACTORS

A statistical analysis of the variables determined from the 12 subsidence features and 17 unsubsided case studies was performed to identify those factors that are most commonly associated with large surface collapses observed within the study area. The primary objectives of the statistical analysis were to identify those variables that are most highly correlated with large surface collapses, and to evaluate the relationships between these variables. These statistical relationships were used to quantify the probability of large surface collapses occurring in areas not evaluated as part of the back-analysis.

A broad class of statistical methods is available to evaluate the relationship between an independent variable, referred to here as a predictor variable, and a dependent variable called an outcome. This class of methods, called generalized linear methods, includes ordinary regression and analysis of variance (ANOVA), as well as multivariate statistics such as analysis of covariance (ANCOVA) and log-linear regression (Agresti, 1996; Menard, 1995). One of these methods, logistic regression, is unique in that it allows prediction of a dichotomous or binary outcome from a set of variables that may be continuous, dichotomous, or categorical. Continuous variables are those that can have a range or continuum of values.

For this study, continuous variables include measured values such as depth to mine stope or thickness of geologic units. Dichotomous variables are binary in nature and usually describe the presence or absence of a feature. In this study, examples of dichotomous variables could include the presence or absence of rockfalls, pillars, chat piles, and tectonic features. Logistic regression is also unique in that the probability of a particular outcome can be estimated as a function of the values of the independent model variables. In the present study, the dependent variable is the state of the surface above the mine workings, either subsided or unsubsided.

Because the selected mine subsidence variables described in Section 6.1.2.1 include both continuous and dichotomous variables, and the desired outcome is binary in nature, logistic regression analysis was selected as the appropriate statistical model for the subsidence evaluation. Appendix E describes the logistic regression equations. Those results are summarized here. For a set of independent variables X_i for $i = 1, 2, 3, \ldots, p$,we want to predict the probability that the dependent parameter has a value of $Y = 1$, which indicates subsidence has occurred. The probability that a mine will collapse is conditioned on a set of independent variables $\mathbf{x} = \{x_1, x_2, \ldots, x_p\}$, and is given by

$$P(Y = 1 \mid \mathbf{x}) = \frac{1}{1 + \mathrm{e}^{-g(\mathbf{x})}}$$

where:

$$g(\mathbf{x}) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_p x_p \, .$$

β_0 is the model intercept, and β_i is the model slope. Development of the logistic regression model requires determination of the intercept, model slopes, and the number of independent variables to use.

The statistical process used to identify the mine subsidence variables that are most highly correlated with large subsidence features (based on the back-analysis) is described in detail in Appendix E. Results of this analysis indicate that the following variables are the most significant for the 12 subsided and 17 unsubsided case studies evaluated during the back-analysis:

- T_{rf}/W_{st} is the ratio of mine-roof thickness to mine-stope width, where mine-roof thickness is the thickness of the Boone Formation and Chester.
- H_{st}/D_{st} is the ratio of the height of stope to the depth of stope.

The resulting equation for $g(\mathbf{x})$ is:

$$g(\mathbf{x}) = 1.704 - 20.937\, T_{rf}/W_{st} + 9.159\, H_{st}/D_{st} \, .$$

6.3 APPLICATION OF PREDICTIVE TOOL

The two-parameter predictive equation developed above is recommended for use by land managers or geotechnical engineers to predict the probability of subsidence. The equation is applicable to mine workings similar to those included in the back-analysis. This equation was used to estimate the probability of subsidence in the study area. The results are discussed in Section 7 of this report.

It must be emphasized that the predictive model does not say anything about when or if subsidence will occur, but rather gives a probability of it happening. Furthermore, the probability does not apply to any particular time period. The probability represents the fraction of sites that are expected to subside of all sites that have specified values of T_{rf}/W_{st} and H_{st}/D_{st} .

6.4 ESTIMATED MAXIMUM SUBSIDENCE

The estimated maximum subsidence has been defined for this study as the maximum amount of subsidence (measured in feet) that could occur at a given surface location as a result of collapse within the underlying mine workings. Collapses start as a failure of the roof material. During this process, the roof material breaks into pieces, and the rubble occupies more volume than the original material. The bulking factor α is the ratio of the volume of the rubble divided by the volume the original material.

TABLE 6.1A
SELECTED VARIABLES RELATED TO SUBSIDED AND UNSUBSIDED CASE STUDIES IN THE PICHER MINING FIELD

Case history number	Mine lease name	Subsided or unsubsided case	Number of mine levels present	Shafts within stope or collapse area	Rock falls noted on map(s)	Pillars removed or trimmed	Chat pile over all or part of stope	Width of stope (ft)	Length of stope (ft)	Maximum unsupported span (ft)	Maximum height of stope (ft)	Depth from surface to top of stope (ft)	Interburden thickness between levels (ft)	Areal extraction ratio	(height of stope)/(thickness of overburden)	Thickness of Boone Formation above stope (ft)	Thickness of Chester above stope (ft)	Thickness of alluvium and shale above stope (ft)	Mapped tectonic/geologic features within or near collapse or stope area
1	Woodchuck	subsided	2	1	no	?	no	115	235	115	114	120	na	1.00	0.95	52	0	68	syn
2	Woodchuck	unsubsided	2	0	no	?	no	105	130	50	25	135	10	0.98	0.19	65	13	57	syn
3	Woodchuck	unsubsided	1	0	no	?	yes	191	258	100	77	173	na	0.98	0.45	28	62	83	syn
4	Domado	subsided	1	2	no	yes	yes	440	740	95	106	115	na	0.88	0.92	10	50	55	syn
5	Domado	unsubsided	1	1	no	yes	yes	217	288	125	71	151	na	0.93	0.47	61	30	60	syn
6	Meteor	subsided	3	1	no	?	no	172	358	60	25	105	30	0.85	0.24	0	30	75	
7	Ritz	subsided	1	0	no	?	no	83	153	24	14	195	na	0.96	0.07	15	0	180	F, syn
8	Ritz	unsubsided	3	0	no	?	no	151	167	69	25	170	8	0.80	0.15	0	16	169	syn
9	Crystal	subsided	3	1	no	?	no	194	207	56	51	165	8	0.78	0.31	0	0	165	syn
10	Crystal	subsided	2	0	?	possibly	no	83	>200	40	37	149	?	0.93	0.25	0	0	149	F, syn
11	Crystal	unsubsided	2	0	no	?	no	80	145	80	110	149	na	1.00	0.74	20	20	115	F, syn
12	Blue Goose 1	subsided	2	0	no	?	yes	340	500	110	77	201	mined out?	0.91	0.38	25	43	132	F, syn
13	Blue Goose 1	unsubsided	1	1	no	possibly	yes	120	400	120	60	210	na	0.98	0.29	45	25	155	F, syn
14	Blue Goose 1	unsubsided	1	0	no	?	yes	300	450	122	82	257	na	0.91	0.32	5	49	193	F, syn
15	Farmington (Lucky Jack)	subsided	3	1	no	yes	no	387	474	156	50	125	na	0.89	0.40	0	51	70	
16	M.W. & M	unsubsided	1	2	no	?	no	317	568	121	54	160	na	0.87	0.34	55	62	43	
17	Discard	subsided	2	1	no	?	no	125	195	116	45	60	35	0.92	0.75	15	9	36	
18	Discard	unsubsided	1	0	no	?	no	173	435	50	10	137	na	0.85	0.07	92	19	26	
19	Martha B	unsubsided	1	0	no	?	no	151	241	47	15	105	na	0.87	0.14	70	25	10	K
20	Admiralty 3	subsided	1	0	no	?	no	54	71	71	15	45	na	1.00	0.33	0	0	45	
21	Admiralty 3	unsubsided	2	0	no	?	no	134	243	111	25	70	90	0.88	0.36	30	20	20	
22	Netta East	unsubsided	1	0	no	?	no	210	404	109	96	156	na	1.0 (K bed)	0.62	36	55	65	
23	Netta East	unsubsided	1	0	yes	?	no	750	>750	204	31	244	na	0.99	0.13	179	0	65	
24	Netta West	unsubsided	2	0	no	?	no	105	320	50	30	170	na	0.81	0.18	0	60	110	
25a	Netta White	unsubsided	1	2	no	No	no	233	313	96	50	146	na	?	0.34	11	44	90	
25b	Netta White	subsided	1	2	no	yes	no	233	313	261	50	146	na	?	0.34	11	44	90	
26	Cardin Townsite north	unsubsided	1	0	no	?	no	200	280	80	8	196	na	0.97	0.04	146	22	33	syn
27	Cardin Townsite south	unsubsided	1	0	no	?	no	80	170	80	22	230	na	0.99	0.10	120	35	75	syn
28	Scammon Hill	subsided	1	0	no	?	no	40	87	40	69	248	na	1.00	0.28	60	17	158	syn

Notes:
(1). F = fault or faulting. fld = fold. K = karst structure. syn= within 1 mi Miami Trough. frac.= fracturing noted in reports
Stope dimensions and depths are with reference to the upper level stope where multiple level mining is present. Combined heights of multi-level stopes are noted in the comments column.
Circular 88 refers to: Luza, 1986, Stability Problems Associated with Abandoned Underground Mines in the Picher Mining Field Northeastern Oklahoma, Oklahoma Geological Survey, Circular 88, 114 pp.

TABLE 6.1B
INFORMATION PERTAINING TO SUBSIDED AND UNSUBSIDED CASE STUDIES IN THE PICHER MINING FIELD

Case History Number	Mine Lease Name	Subsided Or Unsudsided Case	Approximate Date Of Collapse	Drill Logs Used For Geologic And Ore Assay Data	Mine Map Used- File Name	Mine Map Date	Comments
1	Woodchuck	subsided	pre-1939	#19c, #21c	oi sene 30-29-23 1-40 1945 Woodchuck O-21 bw 1-1 okspn83usft.tif	8-24-45	165 ft circular surface collapse, pre-1939. Upper mine level collapse. Stable since 1952. #35 on Plate 2, Circular 88. Two levels mined in area, but only upper level mined in area of collapse.
2	Woodchuck	unsubsided	na	#37	ep sene 30-29-23 1-50 Woodchuck 1965 okspn83usft.tif	9-24-65	25 ft upper stope, 57 ft lower stope. Measurements made on upper stope. Combined stope heights = 82 ft. Stacked pillars.
3	Woodchuck	unsubsided	na	#120	ep sene 30-29-23 1-50 Woodchuck 1965 okspn83usft.tif	9-24-65	Chat pile located over stope.
4	Domado	subsided	1952-1964	#32	rm swnw 29-29-23 1955 1-50 Domado E-255 okspn83usft.tif	10-10-55	Large 550 by 400 ft surface collapse. Two shafts within collapse, #1 and #2 on Plate 2, Circular 88. 1966 American Zinc Co. map shows collapse to surface. Chat pile over part of stope.
5	Domado	unsubsided	na	Spry #1	az swnw 29-29-23 1966 1-50 Domado okspn83usft.tif	10-15-66	Chat pile over small part of stope.
6	Meteor	subsided	1939-1952	4A	ok458n_clp_okspn83usft.tif	11-6-56	300 by 168 ft surface collapse, #30 on Plate 2, Circular 88. Stable since 1980. Upper stope 25ft, middle stope 10 ft, lower stope 30 feet. Combined stope heights = 65 ft. Working heights inferred from drill logs.
7	Ritz	subsided	unknown	x-117, x-120	ok435n_clp_okspn83usft.tif	1-31-56	Previously unrecognized surface collapse. Approximately 100 ft circular pond area about 23 ft deep. Smaller collapse feature just to south.
8	Ritz	unsubsided	na	#38	ok435n_clp_okspn83usft.tif	1-31-56	Three levels evenly distributed, stacked pillars. Upper level stope used for measurements. Upper stope 25ft, middle stope 23 ft, lower stope 20 ft. Stope heights inferred from drill logs.
9	Crystal	subsided	pre-1939	#P52, #12, #13	ep sesw 19-29-23 1964 1-50 Crystal Central okspn83usft.tif	11-11-64	170 by 210 ft surface collapse, #47 on Plate 2, Circular 88.
10	Crystal	subsided	1964-1972	H-3, 50, 118,128	ep swsw 19-29-23 1956 1-50 Harrisburg okspn83usft.tif & ep sesw 19-29-23 1964 1-50 Crystal Central okspn83usft.tif	4-12-56 & 11-11-64	160 by 72 ft surface collapse, #1504 on Plate 2, Circular 88. Pillars may be gone. Complex geology and faulting in area. Appears to be upper level collapse, no main level mining below stope.
11	Crystal	unsubsided	na	#37	ep sesw 19-29-23 1964 1-50 Crystal Central okspn83usft.tif	11-11-64	Large stope, encompassing two mining levels. Complicated faulting. Collapse immediately to south is not over the large stope.
12	Blue Goose 1	subsided	1952-1964	#32, #87	ok435n_clp_okspn83usft.tif	1-31-56	300 by 300 ft surface collapse, #1511 on Plate 2, Circular 88. Very complex geology. 155 ft high chat pile was over collapse area.
13	Blue Goose 1	unsubsided	na	#7	ok435n_clp_okspn83usft.tif	1-31-56	Chat pile over part of stope. Max. unsupported span drawn from 1965 Eagle-Picher Blue Goose No. 1 Mine map, 1which does not show a pillar at location of measurement.
14	Blue Goose 1	unsubsided	na	#78	ok435n_clp_okspn83usft.tif	1-31-56	

TABLE 6.1B
INFORMATION PERTAINING TO SUBSIDED AND UNSUBSIDED CASE STUDIES IN THE PICHER MINING FIELD

Case History Number	Mine Lease Name	Subsided Or Unsudsided Case	Approximate Date Of Collapse	Drill Logs Used For Geologic And Ore Assay Data	Mine Map Used-File Name	Mine Map Date	Comments
15	Farmington (Lucky Jack)	subsided	1964-1972	F-5 and F-11	ok477n_clp_okspn83usft.tif	12-28-54	120 by 120 ft surface collapse, #1517 on Plate 2, circular 88. Multiple mine levels in area, but only 1 level below collapse. "Bouldery" Chester present.
16	M.W. & M	unsubsided	na	CC-3	ok477n_clp_okspn83usft.tif	12-28-54	"Bouldery" ground present.
17	Discard	subsided	pre-1939	C-4	ok474n_clp_okspn83usft.tif	3-31-55	150 by 200 ft surface collapse, #1501 on Plate 2, circular 88. Complex multi-level mining - some narrow stopes up to 70 ft. high. Upper stope 20ft, lower stope 25 ft. Working heights inferred from drill log assay data.
18	Discard	unsubsided	na	C-51	ok474n_clp_okspn83usft.tif	3-31-55	Based on drill log C-51 located approx. 300 ft northwest of location (geology appears uniform).
19	Martha B	unsubsided	na	#45	ok474n_clp_okspn83usft.tif	3-31-55	Possible karstic area. Small collapse to north just across state line road possibly due to surface water runoff into karstic terrain. KDOT has drill core.
20	Admiralty 3	subsided	unknown	#368	ok434s_clp_okspn83usft.tif	9-6-56	Two mine levels in area, but only one level under collapse. #1549 on Plate 2, Circular 88. Much lateral variability in ore grade.
21	Admiralty 3	unsubsided	na	#350	ok434s_clp_okspn83usft.tif	9-6-56	
22	Netta East	unsubsided	na	#59	Netta E EP ne ne 20-29-23 1-50 Frasier 8-14-67 al35 bs13 okspn83usft.tif	8-14-67	Three mine levels in area, but combined into one large stope in study area. Reunion Park location.
23	Netta East	unsubsided	na	#42	Netta E EP ne ne 20-29-23 1-50 Frasier 8-14-67 al35 bs13 okspn83usft.tif	8-14-67	Large areas of rockfall in this area of mine, but no surface collapse.
24	Netta West	unsubsided	na	#1190	Netta W EP nw ne 20-29-23 1-50 Frasier 8-14-67 al35 bs5 okspn83usft.tif	8-14-67	Two levels in area, but only one level in the stope measured.
25a	Netta White	unsubsided	1966	2F	ep swse 17-29-23 1965 1-50 Netta White okspn83usft.tif	8-19-65	Non-collapse case, but surface collapse occurred after shaft pillar(s) shot in 1966.
25b	Netta White	subsided	1966	2F	ep swse 17-29-23 1965 1-50 Netta White okspn83usft.tif	8-19-65	Same as 26a - <u>collapsed after pillar(s) shot in 1966</u>. Assume all pillars near shaft were removed. Collapse apparently occurred about 8 hours after pillars were shot.
26	Cardin Townsite north	unsubsided	na		ep sese 19-29-23 1966 1-50 Cardin Townsite okspn83usft.tif	1966	Max room height 14' (60' x 100' rooms), systematic pillars 20'x30' @ 60'+/- O.C., sheet ground mined w/ few exploration ramps to M bed, Chester 17-27' thk.
27	Cardin Townsite south	unsubsided	na		ep sese 19-29-23 1966 1-50 Cardin Townsite okspn83usft.tif	1966	G and H beds mined in one level, one narrow ramp to K bed for explor., Boone roof 115-120, thick., Chester 33-35' thick., pillar size varies, many very small (10x20' +/-).
28	Scammon Hill	subsided	post 1983	#96	ok407s_clp_okspn83usft.tif	8-13-58	Deep trough area (30 feet deeper than surrounding floor)of narrow mine workings. Nearby drill logs note presence of crevices in mine area.

Note:
Circular 88 refers to: Luza, 1986, Stability Problems Associated with Abandoned Underground Mines in the Picher Mining Field Northeastern Oklahoma, Oklahoma Geological Survey, Circular 88, 114 pp.

As the collapse progresses upwards it can either reach the surface if the increase in volume is less than the volume of the mine stope, or it will stop if the volume increase is greater than the increase mine stope volume. The amount of surface deformation is calculated based on the stope heights, the thickness of the geologic units above the stope, and the bulking factors of these geologic units.

The potential maximum subsidence or potential subsidence depth (PSD) can be calculated by the following equation:

$$PSD = \max(H_{st} + D_{st} - \sum_{layers} \alpha_l T_l, 0)$$

where H_{st} is the height of stope, D_{st} is the depth of stope, and α_l and T_l the bulking factor and thickness of layer l, respectively. For the simplified three-layer geology of the Picher Mining Field, this equation becomes $PSD = \max(H_{st} + D_{st} - \alpha_{as}T_{as} - \alpha_{ch}T_{ch} - \alpha_{bn}T_{bn}, 0)$
where

T_{as} is the thickness of the alluvium/shale,

T_{ch} is the thickness of the Chester, and

T_{bn} is the thickness of the Boone Formation,

and

α_{as} is the bulking factor of the alluvium/shale,

α_{ch} is the bulking factor of the Chester, and

α_{bn} is the bulking factor of the Boone Formation.

All of the bulking factors are assigned values of 1.2 based on information provided in Section 4.5.3.

Input variables included in the above equations were defined and calculated as follows:

- H_{st} = height of stope = mine roof elevation – mine floor elevation. In areas where there are multiple layers of mine workings, the stope heights of each layer were summed to create a composite stope height.
- T_{as} = thickness of alluvium/shale = ground-surface elevation – top of Chester elevation. (Note: where the Chester is absent, the elevation of the top of the Boone Formation was used.)
- T_{ch} = thickness of Chester = top of Chester elevation – top of Boone Formation elevation
- T_{bn} = thickness of Boone Fm = top of Boone Formation elevation – elevation of mine workings roof. In areas where there are multiple levels of mine workings, it was assumed that any interbeds are in the Boone Formation. The thickness of each of the interbed zones was then summed with the thickness of the Boone Formation above the highest mine layer to create a composite Boone Formation thickness raster.

This methodology for computing the potential maximum subsidence assumes that the collapse occurs as a chimney failure into the mine workings. It assumes that collapse rubble falls directly below the portion of the roof from which it came. In addition, it assumes that material outside the footprint of the collapse does not occupy any of the pre-collapse void space. This method is not applicable for prediction of subsidence from shaft collapses.

6.5 SECTION 6 REFERENCES

Agresti, 1996, An Introduction to Categorical Data Analyses. John Wiley and Sons, Inc.

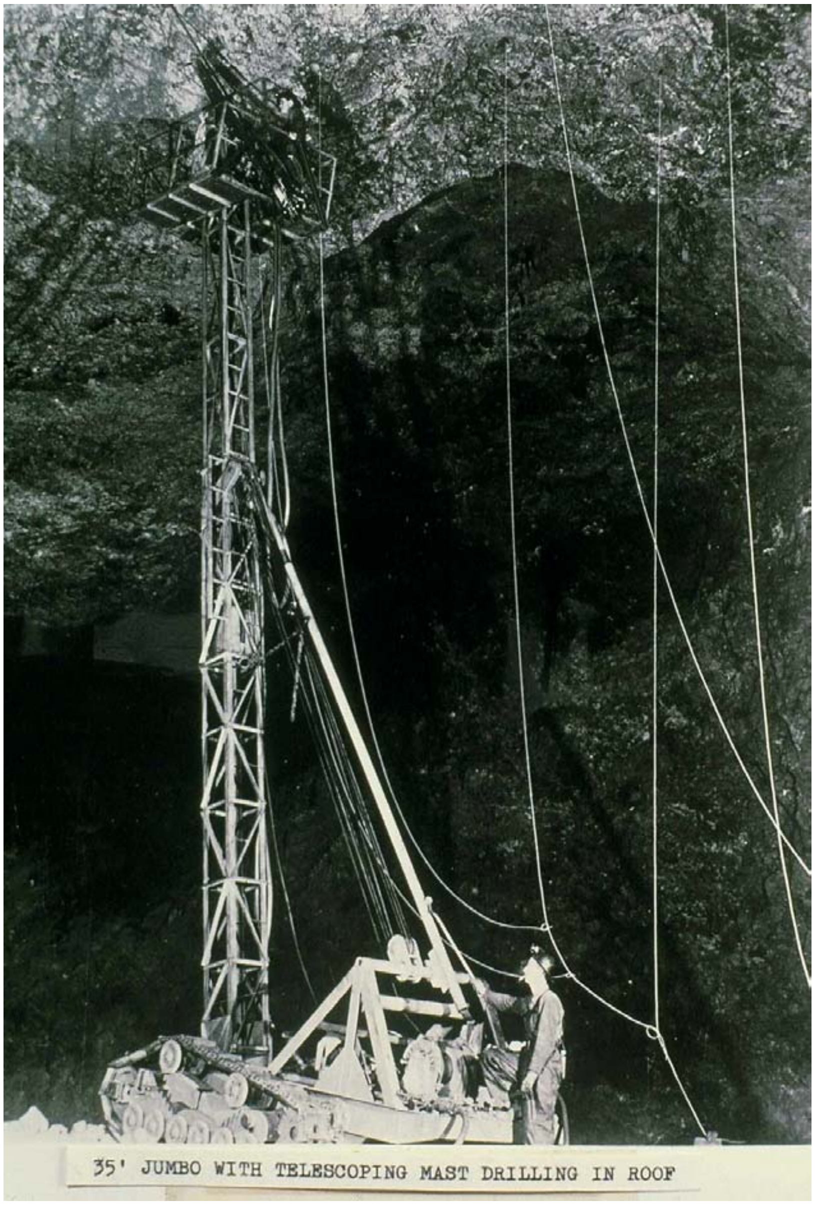
Luza, K. V., 1986. Stability Problems Associated With Abandoned Underground Mines in the Picher Mining Field, Northeast Oklahoma, Oklahoma Geological Survey, Circular 88. 114 pp.

Menard, S. 1995. Applied Logistic Regression Analysis. Sage Publications. Series: Quantitative Applications in the Social Sciences, No. 106.

Oklahoma Governor Frank Keating's Tar Creek Superfund Task Force Final Report, October 2000, prepared by the Office of the Secretary of Environment, Unpublished Report.

Insert Figure 6.1, *Location of the Back-Analysis Case Studies*

7 Results



The Eagle-Picher Mining & Smelting Company developed a "Jumbo" in 1950 with a 35-foot telescoping mast and work platform at the top for the drills and drillers to remove additional ore from the mine roof, pillars, and walls. Note the dynamite fuses extending from the roof to the floor of the mine.

7. RESULTS

The economy of northeastern Oklahoma has always been integrally linked to the mining industry. With the cessation of mining in 1970, the area was left with environmental and health related issues as well as hazards related to subsidence and open mine shafts associated with extensive underground mine workings. The mining legacy has had a negative impact on the area and made it difficult to promote industrial, commercial, or residential growth. The history of the Picher Mining Field has shown that subsidence has had a detrimental effect on public safety, the local environment, and land use options. Specifically, subsidence has resulted in:

- Damage and destruction to homes
- Damage to community water systems, highways, and county roads
- Impacts on the local environment
- Exposure of residents to injury and death
- Altered natural drainage systems
- Restrictions on land use imposed by mining companies and governmental agencies
- Decrease in property values

Until recently, there had never been an attempt to develop a comprehensive understanding of the potential impacts of past and future subsidence on public safety, the local environment, and land use options within the Picher Mining Field. The subsidence evaluation presented in this report is a major step in developing a more complete understanding of the mechanisms and ultimate impacts of subsidence at the site.

To address the above concerns, the Subsidence Evaluation Team developed products to estimate the location, extent, magnitude and probability of future mine subsidence in the study area. A method for calculating the magnitude of subsidence and the probability of subsidence in the study area is to be used as a basis for future investigation of subsidence in the Picher Mining Field. These products are:

- Exhibits that depict the location of mine workings, shaft locations, non-shaft related subsidence, roof falls, and the estimated maximum subsidence from mine workings combined into one map per section
- A logistic regression-based method that can be used to evaluate the probability of subsidence based on pre-1973 major subsidence at specific locations of interest
- Figures that present the results of the analytical tool used to evaluate the probability of subsidence at locations determined to be at or adjacent to transportation corridors and residences or structures to be used as a tool for prioritization of areas for further assessment and mitigation

It is important for the reader of this report to understand both the limitations of and confidence in the data and modeling process used in this evaluation. The short timeframe of the study, the size and complexity of the data set for the overall study area, and the complex process of deriving and applying the analytical tools used in this study lead to the following discussion.

Limitations of the Data and Modeling Process: The following are limitations of the data and the modeling process used in this evaluation:

- Some maps used may not accurately portray the final extent of mining. In some cases, it was found that earlier detailed mine maps contained mine level information, elevations, and roof falls that were sometimes absent from later maps. Additionally, where roof falls were identified, often roof elevation data was absent or sparse, thereby requiring interpolation of floor and roof elevations over large areas. Confidence in the model decreases in areas of sparse data.

- Complexity and ambiguity of the mine maps in some areas resulted in subjective interpretation of details of stope configuration for both back-analysis and forward-analysis. The determination of stope boundaries was often subjective.
- The back-analysis was based mostly on mining-era subsidence. The times of subsidence for two back-analysis case studies, the Ritz and Admiralty case studies, are unknown. Large post-mining-era subsidence cases were not evaluated because many, if not all, of the recent collapses are in areas for which there is limited borehole or mine map data.
- Since the inundation of the mine workings with water, actual verification of mine conditions, e.g., actual mine workings boundaries, the presence or absence of pillars, and verification of roof elevations, was not possible in the time frame allowed for the evaluation and without an extensive drilling and underwater sonar or video surveying program.

Confidence in the Data: Primary data sets utilized in the modeling process were the most recent available detailed mine maps produced by the various mining companies as well as the available exploratory drillers' logs from the era. The following discuss the confidence in these data sets used in this evaluation:

- Both of these data sets (mine maps and drillers' logs) were developed by the mining companies for use in determining ore reserves and prospecting tools, posting survey information for the ground surface and underground openings, and determining mine development. These data sets were assumed to be accurate for their intended purposes.
- Mine maps and borehole logs developed by the mining companies were the only data that was consistently available over the extensive area evaluated. Therefore, the map and borehole log data is the best information available on the extent and depths of the mine workings.
- Mine shaft locations shown on the exhibits were compiled by the OGS. Coordinates were determined from field surveys using Global Positioning System (GPS) technology and/or geo-referenced mine maps.
- An extensive amount of borehole information (3,800 boreholes) was used to develop geologic contacts in the GIS model.
- Quality assurance and quality control checks were performed on the floor and roof elevation data going into the model. The GIS model uses geo-referenced positioning data that was subjected to quality assurance procedures.
- To validate the geologic contact information, a contour map of the Boone-Chester Formation was compared with published geologic structure maps (McKnight and Fischer, 1970). Based on this comparison, the GIS data and the structure maps in McKnight and Fischer (1970) were found to be in agreement.

Confidence in the Modeling Process: The following approaches and assumptions used in the modeling process are conservative and lend confidence to the modeling process:

- The choice of a bulking factor for the overburden rock of 1.2 is conservative relative to published values of 1.3 to 1.5 for similar rock types. The model is therefore expected to over predict the amount and extent of subsidence.
- The two-parameter logistic-regression model is conservative because it does not rely on pillar information. The model instead utilizes stope width, which eliminates the uncertainty associated with the condition, presence, or absence of pillars.

- Shafts and existing subsidence features were accurately located into the model based on coordinate information. Visual checks were performed to verify accurate location.
- A large number (3,800) of borehole logs and optimal spacing of borehole data were used to define the near surface and subsurface geology.
- Buffer zones around shafts and areas of potential subsidence lend conservatism to the model results.
- The back-analysis utilized collapse case studies that occurred during the period of active mining prior to the flooding of the mines. It is believed that the buoyancy effect from the current flooded mine conditions may decrease the potential for subsidence, thereby lending conservatism to the model results.
- Confidence in predictions made by the model is good in areas where there is an adequate density of mine roof elevations, mine floor elevations, and geologic contact information from the mine maps and borehole logs.

Presentation of Results: To understand the potential effects of subsidence throughout the study area, it is necessary to know the location and extent of mine workings and how they relate to the location of surface features that may be affected by subsidence. To illustrate the relationship of mine workings to surface features, the location of mine workings, shaft locations, non-shaft subsidence features, and roof falls are overlaid on high-resolution aerial photography in the exhibits included within this report. Each exhibit covers a single section in Township 29N, Ranges 23E and 24E, presented at a scale of 1 inch = 200 feet. These exhibits are named based on section numbers. For example, Exhibit 20 covers Section 20, Township 29N, Range 23E. The only exhibit that covers a section in Township 29N, Range 24E is Exhibit 19R24. The presentation of the estimated maximum subsidence for the study area was combined on the exhibits with the location information. These exhibits provide information to help locate surface features, such as roads, houses, schools, and other structures, in relationship to underground mine workings, and the approximate location and estimated maximum subsidence (i.e., magnitude of vertical settlement of the ground) if the mine workings were to collapse.

7.1 COMPARISON OF ESTIMATED MAXIMUM SUBSIDENCE MODEL WITH OBSERVED NON-SHAFT RELATED SUBSIDENCE AREAS

Within the study area, a total of 15 historical non-shaft related subsidence features have been documented. The locations of these features are depicted on the exhibits as unnumbered yellow circles. The Estimated Maximum Subsidence Model that was developed as part of this study indicated that subsidence could occur at nine of these locations. For the other six locations the model indicated that there was no potential for subsidence. These six subsidence events are described below:

- Two adjacent subsidence areas (could be considered the same collapse) in Section 19, T29N, R23E at the Ritz Lease. The nearest predicted surface expression is approximately 200 feet away from this location (see Exhibit 19).
- One subsidence area in Section 19, T29N, R23E at the Ritz Lease in the Ritz chat pile. The nearest predicted surface expression is approximately 400 feet away from this location (see Exhibit 19).
- One subsidence area in Section 20, T29N, R23E at northwest corner of the Kenoyer chat pile on the Kenoyer Lease. The nearest predicted surface expression is approximately 300 feet from this location (see Exhibit 20).
- One subsidence area in Section 21, T29N, R23E at the South Bingham Lease near 5th and Alta streets in Picher. The nearest predicted surface expression is approximately 150 feet from this location (see Exhibit 21).

- One subsidence area in the Lucky Jenny Lease in Section 14, T29N, R23E. The nearest predicted surface expression is approximately 170 feet from this location (see Exhibit 14).

There are several possible reasons why the model did not identify these areas as locations of potential subsidence. For the Kenoyer subsidence location in Section 20 in Picher there was a lack of mine floor and/or roof elevation information from the source mine map used to create the spatial mine workings data. Roof elevation information was missing from these mine maps because of the presence of a large roof fall. The South Bingham subsidence in Section 21 is a three-foot diameter by two-foot deep collapse that, because of its small size, may be related to a borehole location and therefore not the result of collapse of mine workings.

Complex multiple-level mine workings that were possibly unmapped or lacked updated mine floor and/or ceiling elevation information from the source mine maps likely resulted in four subsidence areas not being predicted by the model. Of these four subsidence areas, three subsidence areas are in Section 19 (west of Cardin) and one subsidence is in Section 14 (Hockerville). These subsidence locations are also in areas where mining typically took place into the Chesterian shale, resulting in less competent roof rock.

All of these reasons stem from the absence of, or high uncertainty in, the data input into the model, and do not reflect on the reliability of the model. The model appears to produce good results in areas where there is adequate and reliable input information. Application of the model in areas of insufficient or questionable data, however, may produce unreliable results. As such, there is a relatively high degree of confidence in the areas identified by the model as subject to possible subsidence, but there is much less confidence that all areas of possible subsidence in the study area have been identified by the model.

7.2 MINE WORKINGS

Mine workings in the study area are depicted in the exhibits by a shaded light brown background. There are numerous places in the study area where mining on several levels was conducted; these areas with multiple levels of mine workings are not distinguished from areas of single-level mining in the exhibits. All of the mine mapping information, including the multiple-mining-level information, has been digitized electronically and is included in the GIS model. Cross-sections representing one mine in Section 20 (Section 20, T29N, R23E) are shown in Figure 7.1. This figure illustrates the spatial relationship of the multiple mine levels that were incorporated in the model. Additionally, it illustrates that multiple mine levels do not necessarily overlap each other.

7.2.1 Location of Mine Shafts

Known mine shaft locations in the study area are presented on the exhibits based on recent mapping information from the OGS (Luza, 2005, personal communication). It is important to note that all mine shafts have the potential to settle to a depth of greater than 50 feet. Shaft dimensions in the Picher Mining Field are typically five feet by seven feet or six feet by six feet. Initial shaft collapses are typically the size of the original shaft but can enlarge to a diameter of thirty feet. Shaft locations are shown on the exhibits as a thirty-foot square around each shaft. This size of shaft symbol was selected to represent the maximum area that could be affected by shaft collapse (see Figure 4.1).

Mine maps used in developing the exhibits indicate numerous mine shafts that do not reach the surface. These mapped shaft openings probably represent winzes, or shafts between underground mining levels, and for that reason were not included on the exhibits.

All mine shafts, plugged or not, are prone to shaft related subsidence. Based on a count of the mapped mine shafts in the exhibits, there are a total of 330 mine shafts within the study area. Of these mine shafts, 77 are in Picher, 3 are in Cardin, 20 are in the area of Hockerville, and 10 are in Quapaw.

Nine mine shafts in the study area are located beneath or within 30 feet of residences or structures. Eight of these are located in the community of Picher and one is located in Quapaw. There is one mine shaft located under or within 30 feet of a major transportation corridor. This shaft is located in Section 31 within 30 feet of S565 Road (Cardin Road). In Section 29, one mine shaft is located under the Cardin sewage lagoon.

7.2.2 Existing Non-Shaft Related Subsidence Features

The locations of non-shaft related subsidence features presented on the exhibits are also based on recent mapping information from OGS (Luza, 2005: personal communication). These features are indicated on the exhibits by a yellow circle at the approximate center of the non-shaft related subsidence feature. It is noted that non-shaft related subsidence features are typically laterally extensive and that the marking circle does not represent the extent of surface disturbance.

7.2.3 Roof Falls

Mine maps included information on the location and extent of roof falls that occurred at some locations. The perimeters of the roof fall locations are represented on the exhibits as a jagged red line. These roof falls indicate that roof failure, hence the caving process, had begun in these areas at the time of mining.

7.3 EXTENT OF MINING IN THE STUDY AREA

The extent of mine workings in the study area is illustrated on Figure 1.1, albeit on a very small scale. Significant portions of the towns of Picher, Cardin, and Hockerville that are located within the study area have been undermined: 34% of Picher, 29% of Cardin, and 11% of Hockerville. Figure 1.1 also shows that 4.5 miles of the 19 miles of major transportation corridors included in the study area are also undermined.

The town of Quapaw is also undermined as evidenced by the presence of mine shafts and mill site locations, but no records were located regarding the extent of mining beneath the town. For this reason, Quapaw was not included in the current evaluation, although mine subsidence hazards may exist in this area.

7.4 ESTIMATED MAXIMUM SUBSIDENCE

The estimated maximum subsidence for each of the areas covered by the study is presented on the exhibits. This value is the maximum subsidence that could be expected at the ground surface, based on the height of the mine workings and the thickness and bulking characteristics of the strata overlying the mine workings. This value was calculated as described in Section 6.4.

The estimated maximum subsidence from mine workings was divided into ranges to classify potential impacts on structures and public safety. These ranges of estimated maximum subsidence from mine workings are shown in Table 7.1, *Effect of Subsidence on Roads, Houses, Structures, Utilities, and Public Safety.*

TABLE 7.1
EFFECT OF SUBSIDENCE ON ROADS, HOUSES, STRUCTURES, UTILITIES, AND PUBLIC SAFETY

Range of Subsidence [feet]	Effect of Subsidence on		
	Roads	Houses, Structures and Utilities	Public Safety
< =2	Can lead to vehicular accident	Damage may be repairable or mitigated	Not likely to cause physical injury; moderate difficulty escaping
2-5		Damage may not be repairable	
5-10		Damage not likely repairable	Likely to cause physical injury and possibly death; difficult to escape without assistance
10-25			
25-50			
>50			

The study area encompasses a total of 4,400 acres. Of this 4,400 acres of the total study area, 1,270 acres are undermined. The estimated maximum subsidence analysis was applied to these undermined areas in the GIS to identify cells where subsidence could occur. The minimum-size area calculated by the GIS was a 10-foot square cell. These cells were grouped into a total of 286 numbered locations and/or clusters based on mine geometry. The locations and/or clusters were numbered on the exhibits for ease of identification in this report. These 286 numbered locations comprise a total of 88 acres of potential subsidence.

Location information, the mine lease name, the affected areal extent, and the range of estimated maximum subsidence for these 286 locations are presented in Table 7.2. These results are also presented graphically on the exhibits. The numeric identifier assigned to each location in Table 7.2 corresponds to the estimated maximum subsidence features shown on the exhibits. Figure 7.2 shows an overview of these locations.

A summary of the 286 numbered locations shown in Table 7.2 by the estimated maximum subsidence within the study area is presented below:

- 26 locations with less than 2 feet of subsidence
- 53 locations with 2 feet to 5 feet of subsidence
- 57 locations with 5 feet to 10 feet of subsidence
- 80 locations with 10 feet to 25 feet of subsidence
- 47 locations with 25 feet to 50 feet of subsidence
- 23 locations with greater than 50 feet of subsidence

The following further analysis is a breakdown of the above-listed locations in relation primarily to residences and structures, public use areas, and transportation corridors at or within 150 feet of a location with an estimated maximum subsidence. The 150-foot distance was chosen as a buffer zone to account for uncertainties in the data and for an estimated angle of draw (estimated side slope angle of propagating subsidence). A subsidence buffer map for the Picher Area at a scale of 1” to 300’ is presented in Appendix F as a tool that can be prepared to depict and communicate this 150 foot buffer around areas with an estimated maximum subsidence.

The summary by location within the study area includes:

- 54 locations under or within approximately 150 feet of residences or structures
- 33 locations under or within approximately 150 feet of major transportation corridors
- 13 locations under or within approximately 150 feet of both residences or structures and major transportation corridors
- 3 locations under or within approximately 150 feet of public use areas (e.g., parks, playgrounds)
- 183 locations under or within approximately 150 feet of other areas or structures not listed above (city streets, rural roads, pasture lands, chat piles, wooded lands, wetlands, and other undeveloped land)

As shown above, most of the areas identified as having a potential for subsidence in the study area are not located beneath residential areas or major transportation corridors. A brief summary of the locations beneath residential areas and major transportation corridors follows.

7.4.1 Residential Areas

The communities of Picher, Cardin and Hockerville, located in the heart of the mining field, are impacted by the potential for subsidence beneath residences, other structures, and city streets.

A summary of potential subsidence in the residential areas (as defined by city limit boundaries, taken from the ODEQ website GIS data viewer) within the study area follows:

Undermined areas within the city limits of Picher with potential subsidence are divided into the following categories:

- 50 locations under or within 150 feet of residences or structures
- 13 locations under or within 150 feet of major transportation corridors
- 49 locations under or within 150 feet of the community's streets
- 3 locations under or within 150 feet of public parks and playgrounds

The summary of the residences or structures and parks and playgrounds that are above or are within 150 feet of the locations and/or clusters of estimated maximum subsidence in Picher includes:

- 139 Residential Structures
- 11 Business Structures
- 13 Public Use Structures/Facilities:
  - 6 churches
  - 1 City Maintenance Facility
  - 1 Lodge Facility
  - 1 Picher Mining Field Museum
  - 4 Parks/Playgrounds
- 159 total residential, business and public use structures. The number does not include the 4 public use parks/playgrounds. Total: 163 structures and public use facilities.
- 11 of the residences and 1 business are abandoned.

One of these subsidence areas is in Reunion Park (location 140). At Reunion Park, the estimated maximum subsidence is greater than 50 feet. Another area of particular concern because of its use by elementary school children is located in Picher, adjacent to the playground east of the grade school. This location (location 139) is in an area of multiple-level mining previously restricted by the Eagle-Picher Mining Company. Estimated maximum subsidence at this location is between 25 and 50 feet. One location (location 141) is a soccer field located south of the Picher Ballfield Complex. Reunion Park, the soccer field and the nearby playground area are located above the Netta Mine. A detailed description of the Netta Mine and its history with regard to concern for subsidence are found in Appendix C.

In addition to Reunion Park, four other areas in Picher have an estimated maximum subsidence of 50 feet or greater. One area is located below the southeast edge of the Vantage chat pile near the intersection of Netta and 4th Streets (location 142), another is located under the St. Joe chat pile on south Main Street (location 148), and two locations are between Main and Connell Streets (Highway 69) north of D Street (locations 262 and 266). As seen in Exhibits 16, 17, 20, and 21, there are numerous other locations having an estimated maximum subsidence of 50 feet or less within the community of Picher.

Undermined areas within the city limits of Cardin with potential subsidence are divided into the following categories:

- 5 locations under or within 150 feet of residences or structures
- 4 locations under or within 150 feet of major transportation corridors
- 1 location under or within 150 feet of the community's streets
- 0 locations under or within 150 feet of public parks and playgrounds

The summary of the residences or structures and parks and playgrounds that are above or are within 150 feet of the locations and/or clusters of estimated maximum subsidence in Cardin includes:

- 33 Residential Structures
- 6 Business Structures
- 3 Public Use Structures/Facilities:
  - 3 churches
- 42 total residential, business and public use structures.
- 3 of the residences and 4 businesses are abandoned.

Two areas have an estimated maximum subsidence of greater than 50 feet: one on the edge of Cardin and south of Picher located south of 12th (East 30 Road) and Tar River Streets (location 87), and the other located in the area just east of the Cardin sewage lagoons (location 83) near the very northwest corner of Section 29. Two areas located to the west of 2nd and Elm Streets (locations 117 and 119) have an estimated maximum subsidence of 25 to 50 feet in depth. One area near the intersection of 2nd and Main Streets in Cardin (location 116) has an estimated maximum subsidence of 10 to 25 feet.

Undermined areas within Hockerville (defined for purposes of this report as the area between 20 Road to the south and State Line Road to the north, and 604 Road to the west and 610 Road to the east) with potential subsidence are divided into the following categories:

- 5 locations under or within 150 feet of residences or structures
- 0 locations under or within 150 feet of major transportation corridors
- 7 locations under or within 150 feet of the community's streets
- 0 locations under or within 150 feet of public parks and playgrounds

The summary of the residences or structures and parks and playgrounds that are above or are within 150 feet of the locations and/or clusters of estimated maximum subsidence in Hockerville includes:

- 4 Residential Structures
- 1 Business Structures
- 1 Public Use Structures/Facilities:
  - 1 church
- 6 total residential, business and public use structures.
- 0 of the residences and 0 business are abandoned.

In the Hockerville area, one location between State Line Road and East 13 Road, just to the west of S 605 Road (location 212), has an estimated maximum subsidence of greater than 50 feet. This area is also the location of an existing non-shaft related collapse at the Farmington mine lease. Additionally, an area at the north end of S 606 Road (location 214) has an estimated maximum subsidence of between 25 and 50 feet. Several other locations in the Hockerville area have an estimated maximum subsidence of 10 to 25 feet.

Undermined rural locations outside of Picher, Cardin, and Hockerville with potential subsidence are divided into the following categories:

7 locations under or within 150 feet of residences or structures

- 29 locations under or within 150 feet of major transportation corridors
- 17 locations under or within 150 feet of rural roads
- 0 locations under or within 150 feet of public parks and playgrounds

- 3 locations under or within 150 feet of railroads

Locations having an estimated maximum subsidence of 50 feet or greater in the rural areas outside of Picher, Cardin, and Hockerville include:

- Location # 70 – South of 12th Street (East 30 Road), west of Highway 69 in Section 29, T29N R23E
- Location # 196 – South of intersection of East 20 Road and South 607 Road in Section 23, T29N R23E
- Location # 11 – South of East 40 Road, east of Highway 69 in Section 33, T29N R23E
- Location # 47 – North of East 40 Road, west of Highway 69 in Section 29, T29N R23E
- Locations # 21, 70, 72, 74, and 78–south of 12th Street (East 30 Road) in Section 29 T29N R 23E
- Locations # 93, 99, 100, 106, and 111–south of East 30 Road, east and west of Cardin Road (South 565 Road) in Section 30, T29N R23E.

7.4.2 Major Transportation Corridors

As indicated earlier, the transportation corridors evaluated in the study area are Highway 69 from the junction of Highways 69 and 69A north through Picher to the Kansas state line, Highway 69A through Quapaw to the Kansas state line, East 20 Road (A Street) from the west side of Picher to the junction with Highway 69A, and the Cardin Road from the junction with Highway 69 in Picher to the junction north of Commerce. In order to evaluate all areas within 150 feet of the transportation corridors listed above, the subsidence evaluation was extended to the section quarter-quarter portion of the mapped mine lease adjacent to the transportation corridors considered.

An evaluation of the locations having potential subsidence for the major transportation corridors shows:

- Within the communities of Picher, Cardin and Hockerville, there are undermined transportation corridors that pass through or border the city limits. Potential subsidence under or within 150 feet of major transportation corridors or city streets in these communities are divided into the following:
- 17 locations where there is estimated subsidence located under or within 150 feet of major transportation corridors within these three communities
- 57 locations under or within 150 feet of city streets in these three communities
- Undermined rural locations outside of Picher, Cardin, and Hockerville, with estimated subsidence are divided into the following categories:
- 29 locations under or within 150 feet of major transportation corridors
- 17 locations under or within 150 feet of rural roads
- locations under or within 150 feet of a railroad

Below is a summary of the locations with potential subsidence under or within 150 feet of major transportation corridors:

- 2 locations with potential subsidence were identified beneath Highway 69A from the junction of Highway 69 and Highway 69A to the Kansas state line. These locations, number 202 in Section 19, T29N R24E (Malsbury Lease), and number 13 in Section 26, T29N R23E (Alice Greenbeck Lease), are located under Highway 69A north of Quapaw. Both of these locations have an estimated maximum subsidence of 10 to 25 feet.

- 22 locations with potential subsidence were identified within 150 feet of and beneath Highway 69 from the junction of Highway 69 and 69A south of Picher to the Kansas state line. Most of these areas are located south of Picher beginning in Sections 28 and 29 and continuing south of Douthat Road into Sections 32 and 33. Estimated maximum subsidence of 50 feet is predicted in several locations near the intersection of Douthat Road and Highway 69 extending north along Highway 69 in Sections 28 and 29 south of Picher. One location within 150 feet of Highway 69 in north Picher (location 266) in Section 17 has an estimated maximum subsidence of greater than 50 feet.
- 18 locations with possible subsidence were identified adjacent to and beneath Cardin Road from Picher to Commerce. Most of these areas are located between the Southside Mine adjacent to the old Eagle-Picher Central Mill and the Cardin city limits. At several locations, the estimated maximum subsidence is 10 to 25 feet.
- 4 locations with estimated subsidence were identified on East 20 Road (A Street) from Highway 69 in Picher east to Highway 69A. At location # 196 located south of the intersection of A Street (East 20 Road) and S 607 Road in Section 23, T29N R23E, the estimated maximum subsidence is greater than 50 feet.

Locations of the list of potential subsidence areas developed by the CY 2000 Keating Task Force were also examined using the process to estimate the amount of subsidence that could occur if these areas were to collapse. The results are presented in Table 7.3, *Evaluation of Subsidence Potential at Areas Identified by Retired Miners in CY2000.* Several of the locations listed (i.e., cases 9, 13 to 15, part of 18, 19 and 20) are not in the current study area. Of the remaining areas, several located in and around Picher have a possible subsidence of 25 feet or greater.

7.5 PROBABILITY OF SUBSIDENCE

As described in Section 6 and Appendix E, an equation was developed from the back-analysis case studies to calculate the probability of future subsidence. The probability was calculated using a logistic regression model. This model does not incorporate any time factor, as the data are insufficient to assess the effect of time. As a result, there is no time interval associated with the probability. All that can be said is that a site with a greater probability is more likely to subside than a site with a lower probability.

The probability of subsidence was evaluated for areas where subsidence, as described in Section 7.3, could occur within 150 feet of residences, structures, or major transportation corridors. For each location the stope width was measured and input into the GIS model to calculate the probability at each 10-foot square cell using the associated geologic and mine geometry values stored there. The results are presented on Figures 7.3A through 7.3K, and are shown in Table 7.4 for all the locations evaluated. Selected locations are discussed in the following sections on impacts.

The evaluation provides a numerical prediction of the probability of future subsidence at these locations based on the similarity in characteristics with those of the collapsed mine workings of the back-analysis case studies. In this context, the evaluation supports the subsidence potential analyses by identifying which of the potential subsidence locations are more likely to collapse, without consideration of any time frame. In other words, a location with a probability near 100% is predicted (highly probable) to subside but it could happen in the next few days, months, years, tens of years, or even hundreds of years.

A total of 133 areas were identified for this probability of subsidence evaluation. The probability analysis is useful as a tool to prioritize locations to be addressed. Figure 7.3A shows an overview of these 133 areas. The model was applied only to cells with greater than nominal estimated maximum subsidence potential. The areas where the probability of subsidence was evaluated were grouped into three categories, shown as different colors on Figures 7.3B through 7.3K. The colors on the figures correspond to the following probability of subsidence ranges:

- Blue =< 20% Probability of Subsidence

- Green = 20 to 50% Probability of Subsidence
- Red => 50% Probability of Subsidence

A site with a greater than 50% probability of future subsidence (colored red) would typically represent a location overlying a mine with a wide stope and/or thin roof rock (Boone Formation and Chester). There are other areas where expression of subsidence may occur; however, the probability of subsidence for these areas was not evaluated since they are not located within 150 feet of residences, structures or major transportation corridors.

Of the 133 areas evaluated for the probability of subsidence, 11 areas had in at least one location within the area a probability of greater than 50%. The following is a discussion of location and affected area/features for these areas with a probability greater than 50%:

- South of East 40 Road, on the Craig Lease, is a 0.40-acre area where the potential subsidence depth is greater than 50 feet in a rural area (see No. 11 in Tables 7.2 and 7.4).
- Under Highway 69, on the Birthday Lease, is a 4.89-acre area where the potential subsidence depth is greater than 50 feet in a major transportation corridor and industrial area (see No. 21 in Tables 7.2 and 7.4).
- Adjacent to Highway 69, on the Skelton Lease, is a 0.53-acre area where the potential subsidence depth is from 25 to 50 feet in a major transportation corridor and near a residence (see No. 42 in Tables 7.2 and 7.4).
- In Cardin, on the Baby Jim Lease, is a 2.70-acre area where the potential subsidence depth is greater than 50 feet in an area that includes residences, city streets and a major transportation corridor (see No. 87 in Tables 7.2 and 7.4).
- Under Cardin Road (South 565 Road), on the Hum-Bah-Wat-Tah Lease, is a 2.48-acre area where the potential subsidence depth is from 25 to 50 feet in a major transportation corridor (see No. 95 in Tables 7.2 and 7.4).
- Adjacent to East 30 Road, on the Ritz Lease, is a 0.04-acre area where the potential subsidence depth is from 2 to 5 feet in a major transportation corridor (see No. 113 in Tables 7.2 and 7.4).
- Under Reunion Park in Picher, overlying the Netta East Mine, is a 2.63-acre area where the estimated potential subsidence is greater than 50 feet in residential and public use areas (see No. 140 in Tables 7.2 and 7.4).
- In Picher, on the West Netta Lease, is a 0.51-acre area where the potential subsidence depth is from 25 to 50 feet in an area that includes residences, city streets, and the youth soccer field (see No. 141 in Tables 7.2 and 7.4).
- In Hockerville, on the Farmington Lease, is a 2.08-acre area where the potential subsidence depth is greater than 50 feet in an area that includes an existing subsidence area and is adjacent to a residence (see No. 212 in Tables 7.2 and 7.4).
- In Picher, on the Netta White Lease, is a 3.24-acre area where the potential subsidence depth is greater than 50 feet in an area that includes an existing subsidence area and is adjacent to residences (see No. 246 in Tables 7.2 and 7.4).
- Adjacent to Highway 69, on the Skelton Lease, is a 0.053-acre area where the potential subsidence depth is from 10-25 feet in a transportation corridor, former flotation pond (see No. 35 in Tables 7.2 and 7.4).

Table 7.2
Summary of Potential Expression of Subsidence Areas, Location and Range of Potential Subsidence

Count	Map ID	Northing	Easting	Quarter, Quarter Section	Quarter Section	Section	Mine Lease	Estimated Maximum Subsidence (feet)	Estimated Area (ac)	Residences or Structures	Public/School Parks and Playgrounds	City Streets and Major Transportation Corridors within Municipal Boundaries	Major Transportation Corridors	Rural Roads	Affected Feature
										p = Picher, c = Cardin, h = Hockerville, rs = rural structure, rtc = rural transportation corridor, r = rural road, rail = railroad					
1	0	724,251	2,894,732	NW	SW	33	John Hunt	10-25	0.172				rtc		East of Hwy 69 in field
2	1	726,043	2,893,591	SE	NE	32	Wesley Smith	5-10	0.018						Pasture Land
3	2	725,313	2,895,720	NW	SW	33	John Hunt	10-25	0.234						Pasture Land south of creek
4	3	725,545	2,895,650	SW	NW	33	Craig	25-50	0.030						Pasture Land
5	4	725,711	2,895,546	SW	NW	33	Craig	2-5	0.002						Pasture Land
6	5	726,248	2,894,958	SW	NW	33	Craig	10-25	0.112					r	Pasture Land
7	6	726,043	2,895,374	SW	NW	33	Craig	25-50	1.166						Pasture Land
8	7	726,415	2,895,445	SW	NW	33	Craig	25-50	1.095					r	Pasture Land
9	8	726,966	2,894,715	NW	NW	33	Craig	5-10	0.280				rtc		Adjacent to Hwy 69, Pasture Land
10	9	727,300	2,895,312	NW	NW	33	Craig	25-50	0.034						Pasture Land
11	10	727,658	2,894,645	NW	NW	33	Craig	25-50	1.219				rtc		Adjacent to Hwy 69
12	11	727,815	2,895,229	NW	NW	33	Craig	> 50	0.399					r	South of 40 Road - Pasture Land
13	12	728,092	2,895,361	NW	NW	33	Craig	10-25	0.034					r	North of 40 Road - Pasture Land
14	13	730,202	2,909,203	NE	SE	26	Alice Greenback	10-25	0.066				rtc		Under Hwy 69 (Alt)
15	14	732,066	2,897,237	NW	NE	28	New Chicago No 1	2-5	0.009						Pasture Land
16	15	732,709	2,896,492	NE	NW	28	Midas	2-5	0.002						Pasture Land
17	16	732,319	2,896,683	NE	NW	28	Midas	10-25	0.076						Pasture Land
18	17	731,972	2,896,502	SE	NW	28	Midas	2-5	0.002						Pasture Land
19	18	732,808	2,894,438	NW	NW	28	Birthday	5-10	0.014						
20	19	732,654	2,895,469	NW	NW	28	Birthday	25-50	0.138						Pasture Land - Adjacent to pond
21	20	732,382	2,895,220	NW	NW	28	Birthday	5-10	0.007						Pasture Land
22	21	732,031	2,894,493	NW	NW	28	Birthday	> 50	5.085				rtc		Industrial area, Under Hwy 69
23	22	731,477	2,894,987	SW	NW	28	Federal-Fort Worth	< 2	0.018						Pasture Land
24	23	731,573	2,894,705	SW	NW	28	Federal-Fort Worth	< 2	0.028						Pasture Land
25	24	731,052	2,894,616	SW	NW	28	Federal-Fort Worth	5-10	0.094						Pasture Land
26	25	730,779	2,894,461	SW	NW	28	Federal-Fort Worth	10-25	0.085				rtc		Adjacent to Hwy 69 - Pasture Land
27	26	730,782	2,894,698	SW	NW	28	Federal-Fort Worth	10-25	0.009						Pasture Land
28	27	730,707	2,894,817	SW	NW	28	Federal-Fort Worth	25-50	0.028						Pasture Land
29	28	730,548	2,894,745	NW	SW	28	Skelton	5-10	0.071						
30	29	730,676	2,895,577	SW	NW	28	Federal-Fort Worth	10-25	0.076						Edge of Lawyers Chat Pile
31	30	730,434	2,895,260	NW	SW	28	Skelton	< 2	0.009						Beneath small chat pile
32	31	730,030	2,895,453	NW	SW	28	Skelton	10-25	0.117						Wooded - adjacent and beneath pond
33	32	729,713	2,895,654	NW	SW	28	Skelton	5-10	0.007						
34	33	729,160	2,894,776	SW	SW	28	Skelton	25-50	0.422						In flotation pond
35	34	729,237	2,894,548	NW	SW	28	Skelton	< 2	0.009						
36	35	729,245	2,894,427	NW	SW	28	Skelton	10-25	0.053				rtc		Adjacent to Hwy 69 - In flotation pond
37	36	729,442	2,894,628	NW	SW	28	Skelton	5-10	0.028						In flotation pond
38	37	729,107	2,895,064	SW	SW	28	Skelton	2-5	0.094						In flotation pond
39	38	728,933	2,894,901	SW	SW	28	Skelton	2-5	0.002						In flotation pond
40	39	728,635	2,894,484	SW	SW	28	Skelton	< 2	0.053				rtc		Wooded
41	40	728,491	2,894,697	SW	SW	28	Skelton	25-50	0.220						Wooded
42	41	728,388	2,894,443	SW	SW	28	Skelton	2-5	0.005				rtc		Adjacent to Hwy 69
43	42	728,204	2,894,527	SW	SW	28	Skelton	25-50	0.583				rtc		Near residence, adjacent to Hwy 69
44	43	727,865	2,893,998	NE	NE	32	Beck	2-5	0.184	rs				r	Residential area, adjacent to 40 Road
45	44	728,396	2,894,285	SE	SE	29	Skelton	5-10	0.005				rtc		Adjacent to Hwy 69, Mine waste area
46	45	728,153	2,893,434	SE	SE	29	Skelton	25-50	0.191					r	Under Chat pile, North of 40 Road
47	46	728,875	2,894,183	SE	SE	29	Skelton	25-50	1.933				rtc		Uinder and adjacent to Hwy 69
48	47	728,560	2,893,624	SE	SE	29	Skelton	25-50	0.319						Under Chat Pile
49	48	728,816	2,893,580	SE	SE	29	Skelton	10-25	0.018						Under Chat Pile
50	49	728,410	2,893,362	SE	SE	29	Skelton	25-50	0.039						Under Chat Pile
51	50	728,612	2,893,329	SE	SE	29	Skelton	10-25	0.117						Under Chat Pile

Table 7.2
Summary of Potential Expression of Subsidence Areas, Location and Range of Potential Subsidence

Count	Map ID	Northing	Easting	Quarter, Quarter Section	Quarter Section	Section	Mine Lease	Estimated Maximum Subsidence (feet)	Estimated Area (ac)	Residences or Structures	Public/School Parks and Playgrounds	Municipal Boundaries within Transportation Corridors and Major City Streets	Major Transportation Corridors	Rural Roads	Affected Feature
										p = Picher, c = Cardin, h = Hockerville, rs = rural structure, rtc = rural transportation corridor, r = rural road, rail = railroad					
52	51	728,666	2,893,094	SE	SE	29	Skelton	10-25	0.028						West Edge of Chat Pile
53	52	729,062	2,893,160	SE	SE	29	Skelton	10-25	0.101						West Edge of Chat Pile
54	53	729,115	2,893,574	NE	SE	29	Skelton	25-50	1.827						Under Chat Pile
55	54	729,179	2,894,068	NE	SE	29	Skelton	< 2	0.039						East Edge of Chat Pile
56	55	729,499	2,894,289	SE	SE	29	Skelton	< 2	0.011				rtc		Adjacent to Hwy 69
57	56	729,724	2,893,691	NE	SE	29	Skelton	10-25	0.202						North side of chat pile, mill pond area
58	57	730,008	2,894,227	NE	SE	29	Skelton	10-25	0.007				rtc		Adjacent to Hwy 69
59	58	729,982	2,894,036	NE	SE	29	Skelton	25-50	0.034						Mine waste area
60	59	730,278	2,894,205	NE	SE	29	Skelton	25-50	0.158				rtc		Adjacent to Hwy 69
61	60	730,286	2,893,892	NE	SE	29	Skelton	25-50	0.921						Mine waste area
62	61	730,215	2,893,313	NE	SE	29	Skelton	25-50	1.111						Mine waste area
63	62	730,477	2,893,411	SE	NE	29	Skelton	< 2	0.053						Wooded area
64	63	730,553	2,893,038	SE	NE	29	Skelton	2-5	0.007						Mine waste area
65	64	731,096	2,893,999	SE	NE	29	Skelton	10-25	0.021	rs					Commercial Building
66	65	731,163	2,893,761	SE	NE	29	Skelton	> 50	0.005						Industrial lot
67	66	731,183	2,893,586	SE	NE	29	Skelton	10-25	0.002						Open area
68	67	731,087	2,892,982	SE	NE	29	Skelton	2-5	0.005						Open area
69	68	731,690	2,892,987	SE	NE	29	Skelton	2-5	0.041						Open area
70	69	732,355	2,893,855	NE	NE	29	Barbara J.	10-25	0.037						Open area
71	70	732,701	2,893,737	NE	NE	29	Barbara J.	> 50	0.517						Open area
72	71	732,954	2,893,175	NE	NE	29	Barbara J.	10-25	0.331					r	Adjacent to 12th st., south side
73	72	732,333	2,893,256	NE	NE	29	Barbara J.	> 50	0.298						Wetland area
74	73	732,181	2,893,049	NE	NE	29	Barbara J.	> 50	0.005						Wetland area
75	74	732,201	2,892,736	NW	NE	29	Barbara J.	> 50	0.507						Wetland area, Near Lytle Creek
76	75	732,464	2,892,415	NW	NE	29	Barbara J.	10-25	0.083						Wetland area, Near Lytle Creek
77	76	732,834	2,892,198	NW	NE	29	Barbara J.	2-5	0.025						Open area
78	77	732,352	2,892,048	NW	NE	29	Barbara J.	2-5	0.007						
79	78	732,196	2,891,886	NW	NE	29	Barbara J.	> 50	0.152						Open area
80	79	732,314	2,891,623	NE	NW	29	Rialto	10-25	0.016						Industrial lot
81	80	732,659	2,891,385	NE	NW	29	Rialto	10-25	0.011						Under Chat Pile
82	81	732,915	2,891,336	NE	NW	29	Rialto	10-25	1.398				rtc		Adjacent to 30 Road (Cardin Road)
83	82	732,444	2,891,058	NE	NW	29	Rialto	25-50	0.376						Under Chat Pile
84	83	732,740	2,890,809	NE	NW	29	Rialto	> 50	0.269						Open area, near Cardin Sewer Lagoon
85	84	733,042	2,890,538	NE	NW	29	Rialto	2-5	0.067				rtc		Adjacent to 30 Road (Cardin Road)
86	85	732,672	2,890,103	NW	NW	29	Baby Jim	25-50	1.956				rtc		Adjacent to Cardin Rd
87	86	732,039	2,889,470	NW	NW	29	Baby Jim	5-10	0.046						Under Chat Pile
88	87	732,745	2,889,133	NW	NW	29	Baby Jim	> 50	2.750	c		c	c		Residential area, under 1st st., adjacent to Tar River st.
89	88	727,087	2,885,043	NW	NW	31	Southside	5-10	0.916						Under Central Mill Chat Pile
90	89	727,260	2,884,712	NW	NW	31	Southside	5-10	0.014				rtc		Adjacent to Cardin Road
91	90	727,422	2,884,645	NW	NW	31	Southside	10-25	0.067				rtc		Adjacent to 565 Road (Cardin Road)
92	91	727,112	2,883,995	NW	NW	31	Southside	25-50	0.624					r	Under 560 Road
93	92	728,825	2,884,513	SW	SW	30	Tom L	5-10	0.055						Under Chat Pile/Mill Pond
94	93	729,896	2,886,159	NE	SW	30	Blue Goose No. 2	> 50	0.739				rtc		Adjacent to 565 Road (Cardin Road)
95	94	730,421	2,885,290	SE	NW	30	HUM-BAH-WAT-TAH	2-5	0.011						Open area
96	95	730,331	2,885,769	SE	NW	30	HUM-BAH-WAT-TAH	25-50	2.679				rtc		Under 565 Road (Cardin Road)
97	96	730,902	2,886,226	SE	NW	30	HUM-BAH-WAT-TAH	5-10	0.207				rtc		Adjacent to 565 Road (Cardin Road)
98	97	730,580	2,886,957	SW	NE	30	Jay Bird	5-10	0.441						Open area/Mine waste area
99	98	730,762	2,886,517	SW	NE	30	Jay Bird	10-25	1.453	rs			rtc		Residential area, adjacent to 565Road (Cardin Road)
100	99	730,612	2,887,616	SW	NE	30	Jay Bird	> 50	0.859						Open area/Mine waste area

Table 7.2
Summary of Potential Expression of Subsidence Areas, Location and Range of Potential Subsidence

Count	Map ID	Northing	Easting	Quarter, Quarter Section	Quarter Section	Section	Mine Lease	Estimated Maximum Subsidence (feet)	Estimated Area (ac)	Residences or Structures	Public/School Parks and Playgrounds	City Streets and Major Transportation Corridors within Municipal Boundaries	Major Transportation Corridors	Rural Roads	Affected Feature
										p = Picher, c = Cardin, h = Hockerville, rs = rural structure, rtc = rural transportation corridor, r = rural road, rail = railroad					
101	100	731,832	2,889,145	SE	NE	30	Woodchuck	> 50	2.470						Wetland area adjacent to Chat Pile
102	101	731,468	2,888,919	SE	NE	30	Woodchuck	> 50	0.059						Wetland area
103	102	730,536	2,889,016	SE	NE	30	Woodchuck	2-5	0.108						Adjacent to Domado collapse
104	103	731,124	2,888,919	SE	NE	30	Woodchuck	10-25	0.009						Adjacent to existing shaft related collapse
105	104	731,110	2,888,808	SE	NE	30	Woodchuck	2-5	0.002						Adjacent to existing shaft related collapse
106	105	731,326	2,888,786	SE	NE	30	Woodchuck	5-10	0.300						Adjacent to Woodchuck chat pile
107	106	731,563	2,888,085	SE	NE	30	Woodchuck	> 50	6.788						Under Woodchuck chat pile
108	107	732,931	2,888,354	NE	NE	30	Lucky Bill	5-10	0.112	c		c	c		Residential area, adjacent to 1st st. (Cardin Road)
109	108	732,870	2,887,672	NW	NE	30	Bennie	2-5	0.060	c		c	c		Residential area, adjacent to 1st st. (Cardin Road)
110	109	732,330	2,887,377	NW	NE	30	Bennie	2-5	0.149	rs					Residential area
111	110	732,599	2,886,977	NW	NE	30	Bennie	10-25	0.397	c		c	c		Residential area, under 565 Road (Cardin Road)
112	111	731,729	2,886,639	NW	NE	30	Bennie	> 50	0.838				rtc		Under 565 Road/Cardin Rd
113	112	731,887	2,885,922	NE	NW	30	Ritz	25-50	1.511						Adjacent to Ritz chat pile and mill pond
114	113	732,752	2,885,427	NE	NW	30	Ritz	2-5	0.048					r	Adjacent to East 30 Road
115	114	734,685	2,888,635	NE	SE	19	John Beaver	< 2	0.002						Pasture
116	115	734,852	2,888,479	NE	SE	19	John Beaver	10-25	0.005						Pasture
117	116	733,399	2,888,249	SE	SE	19	Townsite	10-25	0.475	c		c			Residential area, under 2nd and Main streets
118	117	733,566	2,886,715	SW	SE	19	John Beaver	25-50	2.982						Large extent, mine waste area, open area
119	118	733,845	2,887,296	SW	SE	19	John Beaver	5-10	0.005						Open area mine waste
120	119	734,095	2,886,909	SW	SE	19	John Beaver	25-50	1.600						Large extent, mine waste area, open area
121	120	734,265	2,887,269	NW	SE	19	John Beaver	5-10	0.099						Wetland area adjacent to ponds
122	121	734,483	2,887,046	NW	SE	19	John Beaver	5-10	0.099						Wetland area adjacent to ponds
123	122	734,627	2,887,006	NW	SE	19	John Beaver	10-25	0.028						Wetland area adjacent to ponds
124	123	734,497	2,886,623	NW	SE	19	John Beaver	10-25	0.021						Mine waste area
125	124	734,694	2,886,335	NW	SE	19	John Beaver	10-25	0.090						Mine waste area, adjacent to two non-shaft collapses
126	125	734,816	2,886,265	NW	SE	19	John Beaver	25-50	0.005						Mine waste area, adjacent to two non-shaft collapses
127	126	734,902	2,886,812	NW	SE	19	John Beaver	10-25	0.131						Wetland area adjacent to ponds
128	127	735,041	2,886,574	NW	SE	19	John Beaver	10-25	0.124						Wetland area adjacent to ponds
129	128	735,395	2,886,379	NW	SE	19	John Beaver	10-25	0.298						Wetland area adjacent to ponds
130	129	735,242	2,887,261	NW	SE	19	John Beaver	2-5	0.055						Under John Beaver chat pile
131	130	735,384	2,887,107	NW	SE	19	John Beaver	10-25	0.073						Under John Beaver chat pile
132	131	735,552	2,887,960	NE	SE	19	John Beaver	10-25	0.064						Under John Beaver chat pile
133	132	735,094	2,888,842	NE	SE	19	John Beaver	2-5	0.126	rs				r	Near residence, adjacent to River Road
134	133	737,235	2,889,068	NW	NW	20	Dorothy Bill No. 2	5-10	0.443	rs				r	Near residence, adjacent to River Road
135	134	737,840	2,889,037	NW	NW	20	Dorothy Bill No. 2	25-50	0.096					r	Adjacent to a non-shaft related collapse
136	135	738,296	2,889,707	NW	NW	20	Dorothy Bill No. 2	5-10	0.064				rtc		Adjacent to 20 Road
137	136	736,793	2,890,357	SE	NW	20	Kenoyer	10-25	0.073						Adjacent to Kenoyer Chat Pile
138	137	736,756	2,891,487	SW	NE	20	Vantage	5-10	0.011	p		p			Residential area, under College Road
139	138	737,157	2,891,235	NE	NW	20	Dorothy Bill No. 2	10-25	0.847	p		p			Residential area, under Cherokee and 3rd streets
140	139	737,856	2,891,839	NW	NE	20	West Netta	25-50	0.634	p	p	p			Residential and School playground area, under Frisco st.
141	140	737,500	2,893,361	NE	NE	20	East Netta	> 50	1.600	p	p	p			Reunion Park and Residential area, under Main and 2nd st.
142	141	737,476	2,892,638	NW	NE	20	West Netta	25-50	0.491	p	p	p			Residential area, under 2nd st., soccer field
143	142	736,728	2,892,709	SW	NE	20	Vantage	> 50	1.139	p		p			Under Vantage Chat Pile, Residential area, under 4th st., adjacent to Netta st.
144	143	736,931	2,892,482	SW	NE	20	Vantage	5-10	0.055			p			Under Vantage Chat Pile
145	144	736,548	2,892,210	SW	NE	20	Vantage	2-5	0.014			p			Wooded
146	146	735,674	2,892,725	NW	SE	20	Golden Hawk	5-10	0.023						Under st. Joe Chat Pile

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Count	Map ID	Northing	Easting	Quarter, Quarter Section	Quarter Section	Section	Mine Lease	Estimated Maximum Subsidence (feet)	Estimated Area (ac)	Residences or Structures	Public/School Parks and Playgrounds	City Streets and Major Transportation Corridors within Municipal Boundaries	Major Transportation Corridors	Rural Roads	Affected Feature
										p = Picher, c = Cardin, h = Hockerville, rs = rural structure, rtc = rural transportation corridor, r = rural road, rail = railroad					
147	147	735,683	2,893,060	NE	SE	20	Premier	2-5	0.009						Under st. Joe Chat Pile
148	148	735,205	2,893,017	NE	SE	20	Premier	> 50	1.958						Under st. Joe Chat Pile
149	149	735,289	2,892,197	NW	SE	20	Golden Hawk	25-50	0.018						Open area adjacent to st. Joe Chat Pile
150	150	734,799	2,892,717	NW	SE	20	Golden Hawk	10-25	0.055						Adjacent to st. Joe Chat Pile
151	151	734,794	2,892,127	NW	SE	20	Golden Hawk	25-50	0.503						Adjacent to Barbara J Chat Pile
152	152	735,411	2,891,240	NE	SW	20	Kenoyer	5-10	0.055	p		p			Residential area, under 6th st., adjacent to Cherokee st.
153	153	734,353	2,891,023	SE	SW	20	Rialto	5-10	2.136	p		p			Extensive area, Residential area, under Ottawa Road
154	155	733,520	2,890,613	SE	SW	20	Rialto	10-25	0.733						Under Rialto Chat Pile
155	156	733,275	2,891,400	SE	SW	20	Rialto	5-10	0.241			p	p		Adjacent to 30 Road (Cardin Road) and College st.
156	157	733,744	2,891,792	SW	SE	20	Barbara J	2-5	0.046						Under Barbara J Chat Pile
157	158	733,914	2,892,221	SW	SE	20	Barbara J	5-10	0.053						Under Barbara J Chat Pile
158	159	733,385	2,892,262	SW	SE	20	Barbara J	25-50	0.354			p	p		Adjacent to Cardin Road/Under Barbara J Chat Pile
159	160	733,269	2,893,476	SE	SE	20	Oko	25-50	0.073			p			In Lytle Creek, adjacent to 12th st.and OKO Chat Pile
160	161	733,815	2,893,501	SE	SE	20	Oko	10-25	0.281						Under OKO Chat Pile
161	162	734,017	2,893,664	SE	SE	20	Oko	10-25	0.000						Mine waste area
162	163	734,192	2,893,922	SE	SE	20	Oko	5-10	0.006	p					Residential area
163	164	734,126	2,893,702	SE	SE	20	Oko	2-5	0.020						Mine waste area
164	165	734,378	2,893,645	SE	SE	20	Oko	5-10	0.018	p		p	p		Under Cardin Road, Residential area
165	166	734,682	2,893,673	NE	SE	20	Premier	10-25	0.769	p		p	p		Residential area, adjacent to Main and Cardin streets
166	167	733,913	2,897,287	SW	SE	21	Royal	25-50	0.110						Under Picher sewage lagoon
167	168	734,815	2,897,364	NW	SE	21	Grace Walker	5-10	0.023						Under small chat pile
168	169	735,001	2,897,037	NW	SE	21	Grace Walker	2-5	0.009						Adjacent to Picher sewage lagoon
169	170	735,558	2,897,171	NW	SE	21	Grace Walker	25-50	0.051						Pasture and Wooded
170	171	733,611	2,896,175	SE	SW	21	Grace Walker	10-25	0.331	p		p			Residential area, near 11th street
171	172	733,478	2,894,906	SW	SW	21	New York	25-50	0.941	p		p			Residential area, adjacent to 12th st.
172	173	733,777	2,895,496	SE	SW	21	Grace Walker	2-5	0.011	p		p			Residential area, adjacent to Ella st
173	174	734,051	2,894,904	SW	SW	21	New York	2-5	0.007						Adjacent to pond
174	175	734,021	2,895,151	SW	SW	21	New York	10-25	0.041						Adjacent to pond
175	176	734,213	2,895,713	SE	SW	21	Grace Walker	2-5	0.007	p		p			Residential area, adjacent to 9th st
176	177	734,261	2,895,421	SW	SW	21	New York	2-5	0.032						Pasture and Wooded
177	178	734,369	2,895,329	SW	SW	21	New York	10-25	0.009						Near Edge of chat pile
178	179	734,340	2,895,763	SE	SW	21	Grace Walker	5-10	0.014	p		p			Residential area, north of 9th st
179	180	734,517	2,895,267	SW	SW	21	New York	2-5	0.048						In Chat Pile
180	181	734,485	2,894,978	SW	SW	21	New York	10-25	0.023						Pasture and Wooded
181	182	734,920	2,895,030	NW	SW	21	Black Hawk	< 2	0.009	p		p			Residential area, adjacent to 7th st
182	183	735,023	2,894,418	NW	SW	21	Black Hawk	5-10	0.009	p		p			Residential area, under Francis st
183	184	735,460	2,894,320	NW	SW	21	Black Hawk	< 2	0.005	p		p			Residential area, adjacent to 6th st
184	185	735,826	2,895,142	NW	SW	21	Black Hawk	10-25	0.055	p		p			Residential area, near intersection of Ethel and 5th streets
185	186	737,593	2,896,366	NE	NW	21	Eudora Whitebird	5-10	0.025						Wooded
186	187	738,098	2,896,259	NE	NW	21	Eudora Whitebird	10-25	0.269						Wooded
187	188	737,482	2,897,123	NW	NE	21	Eudora Whitebird	< 2	0.014						Wooded
188	189	737,600	2,898,850	NE	NE	21	No. 1 Black Eagle	5-10	0.016						Pasture and Wooded
189	190	737,741	2,898,704	NE	NE	21	No. 1 Black Eagle	< 2	0.025						Wooded, adjacent to and under pond
190	191	737,571	2,899,405	NE	NE	22	Indiana	5-10	0.333					r	Adjacent to Road 590

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										p = Picher, c = Cardin, h = Hockerville, rs = rural structure, rtc = rural transportation corridor, r = rural road, rail = railroad					
191	192	738,092	2,899,577	NW	NW	22	Dardene	5-10	0.255						Pasture and Wooded
192	193	738,087	2,904,551	NE	NE	22	Indiana	< 2	0.011					r	Wooded and Pasture, adjacent to Road 600
193	194	738,499	2,904,253	NE	NE	22	Indiana	5-10	0.193						Pasture, Mine waste area
194	195	738,537	2,908,025	NW	NE	23	Aztec	25-50	0.069						Pasture, Mine waste area
195	196	738,737	2,908,540	NW	NE	23	Aztec	> 50	0.363	rs			rtc		Residences nearby, adjacent to A st.
196	197	737,774	2,912,725	SW	NE	24	St. Louis No. 4	25-50	0.080				rail		Adjacent to RR tracks
197	198	737,965	2,913,097	NW	NE	24	St. Louis No. 4	10-25	0.041				rail		Adjacnet toRailroad, Pasture and Wooded
198	199	738,317	2,913,265	NW	NE	24	St. Louis No. 4	25-50	0.161				rail		Adjacent to RR tracks
199	200	737,971	2,914,150	NE	NE	24	St. Louis No. 4	2-5	0.011						Edge of Chat Pile
200	201	737,986	2,914,762	NE	NE	24	St. Louis No. 4	10-25	0.112						Under Chat Pile
201	202	738,165	2,918,416	NW	NE	19R24	Malsbury	25-50	0.073				rtc		Large area extending under Hwy 69A
202	204	739,514	2,914,723	SE	SE	13	Scott	10-25	0.011						In Field
203	205	739,875	2,913,138	SW	SE	13	Niday No. 1	10-25	0.057						
204	206	740,369	2,913,205	NW	SE	13	Scott	10-25	0.110						
205	207	743,035	2,908,780	SE	NE	14	Farmington	10-25	0.099			h			Adjacent to state Line Road, under mine waste
206	208	742,858	2,908,231	SW	NE	14	Farmington	2-5	0.085						Close to residential area
207	209	741,766	2,907,094	NE	SW	14	Dobson	10-25	0.962						Farm ground
208	210	742,176	2,907,277	SE	NE	14	Farmington	5-10	0.023						Pasture
209	211	742,381	2,907,237	SE	NE	14	Farmington	10-25	0.057						Pasture
210	212	742,323	2,907,608	SE	NE	14	Farmington	> 50	2.222	h		h			Existing collapse, adjacent to residence
211	213	741,742	2,907,554	NW	SE	14	Lucky Jenny	10-25	0.101	h					Residential area
212	214	742,046	2,908,152	SE	NE	14	Farmington	25-50	0.310	h					Residential area
213	215	741,733	2,908,613	NE	SE	14	Lucky Jenny	10-25	0.005			h			Under dirt Road 013, close to residential
214	216	741,338	2,907,971	NW	SE	14	Lucky Jenny	5-10	0.009						Wooded, close to residences
215	217	738,995	2,906,571	SE	SW	14	Dobson	2-5	0.028				rtc		Existing collapse, adjacent to East 20 Road/A st
216	218	740,394	2,908,673	NE	SE	14	Lucky Jenny	5-10	0.002	h					Pasture, near residence
217	219	740,479	2,908,405	NW	SE	14	Lucky Jenny	< 2	0.002			h			Wooded, near mine waste
218	220	739,841	2,908,316	SE	SE	14	Niday No. 1	10-25	0.067	h		h			Under Residence near 606 Rd.
219	221	740,446	2,907,769	NW	SE	14	Lucky Jenny	10-25	0.631			h			Pasture, under dirt Road 605
220	222	740,704	2,907,441	NW	SE	14	Lucky Jenny	25-50	0.145			h			Near residence, under dirt Road 604
221	223	740,139	2,906,889	SE	SW	14	Dobson	2-5	0.057						Pasture
222	224	739,927	2,904,663	SE	SW	14	Dobson	< 2	0.007					r	Pasture, adjacent to dirt Road 600
223	225	739,616	2,902,673	SE	SE	15	Brewster	2-5	0.018						Pasture
224	226	739,530	2,901,455	SE	SW	15	Beck	5-10	0.023						On edge of Beck Chat Pile and under pond
225	227	739,655	2,894,271	SE	SW	16	Eudora Whitebird	10-25	0.126	p		p			Residential area, under to Francis Road
226	228	740,403	2,894,299	NW	SW	16	Commonwealth	2-5	0.007	p		p			Residential area
227	229	741,169	2,894,687	NW	SW	16	Commonwealth	< 2	0.099	p		p			Residential area, adjacent to Alta Road
228	230	741,469	2,894,024	SE	NW	16	Swift	2-5	0.050	p		p	p		Residential area, adjacent to Hwy 69
229	231	742,696	2,893,963	SW	NW	16	Swift	< 2	0.009	p		p	p		Residential area, near intersection of Hwy 69 and A st.
230	232	738,522	2,892,104	SW	SE	17	Netta White	10-25	0.057	p		p			Residential area, under Vantage Road
231	233	738,685	2,892,476	SW	SE	17	Netta White	< 2	0.016	p		p			Residential area
232	234	738,802	2,892,127	SW	SE	17	Netta White	10-25	0.165	p		p			Residential area, under Vantage Road
233	235	738,987	2,890,196	SE	SW	17	Piokee	2-5	0.021						Pasture
234	236	739,106	2,891,038	SE	SW	17	Piokee	< 2	0.005						Pasture
235	237	739,132	2,890,869	SE	SW	17	Piokee	2-5	0.005						Pasture, Mine waste
236	238	739,534	2,891,004	SE	SW	17	Piokee	10-25	0.002						Pasture, Mine waste
237	239	739,285	2,890,848	SE	SW	17	Piokee	2-5	0.092						Pasture, Mine waste
238	240	739,317	2,890,378	SE	SW	17	Piokee	< 2	0.009						Pasture
239	241	739,440	2,890,427	SE	SW	17	Piokee	5-10	0.016						Pasture
240	242	739,528	2,890,689	SE	SW	17	Piokee	10-25	0.101			p			Adjacent to Ottawa Road, mine waste

Table 7.2
Summary of Potential Expression of Subsidence Areas, Location and Range of Potential Subsidence

Count	Map ID	Northing	Easting	Quarter, Quarter Section	Quarter Section	Section	Mine Lease	Estimated Maximum Subsidence (feet)	Estimated Area (ac)	Residences or Structures	Public/School Parks and Playgrounds	City Streets and Major Transportation Corridors within Municipal Boundaries	Major Transportation Corridors	Rural Roads	Affected Feature
										p = Picher, c = Cardin, h = Hockerville, rs = rural structure, rtc = rural transportation corridor, r = rural road, rail = railroad					
241	243	739,595	2,890,458	SE	SW	17	Piokee	5-10	0.030			p			Under Ottawa Road, mine waste
242	244	739,603	2,891,180	SE	SW	17	Piokee	5-10	0.023						Pasture on edge of Ottawa Chat Pile
243	245	739,414	2,891,808	SE	SE	17	Netta White	10-25	0.037						On edge of Ottawa Chat Pile
244	246	738,918	2,891,530	SW	SE	17	Netta White	25-50	3.471	p					Residential area, existing collapse feature
245	247	741,019	2,892,188	NW	SE	17	Otis White	< 2	0.002						Mine waste area, adjacent to Ottawa Chat pile
246	248	739,839	2,892,234	NW	SE	17	Otis White	2-5	0.005						On edge of Ottawa Chat Pile
247	249	739,793	2,891,690	NW	SE	17	Otis White	25-50	3.012						Large area of expression in Ottawa Chat Pile
248	250	740,037	2,892,175	NW	SE	17	Otis White	2-5	0.096						Under Ottawa Chat Pile
249	251	740,655	2,892,180	NW	SE	17	Otis White	5-10	0.083						Under Ottawa Chat Pile
250	252	740,617	2,892,706	NE	SE	17	Big Chief	10-25	0.032	p		p			Residential area
251	253	740,209	2,892,583	NW	SE	17	Otis White	2-5	0.090	p		p			Residential area, adjacent to Netta Road
252	254	740,059	2,892,421	NW	SE	17	Otis White	2-5	0.016	p					Wooded area adjacent to Ottawa Chat Pile
253	255	739,460	2,892,377	SW	SE	17	Netta White	25-50	0.411	p		p			Near residential area
254	256	739,476	2,892,720	SW	SE	17	Netta White	10-25	0.037	p		p			Residential area, adjacent to Netta Road
255	257	739,681	2,893,218	SE	SE	17	Crawfish	10-25	0.051	p		p			Residential area
256	258	739,622	2,892,875	SE	SE	17	Crawfish	2-5	0.051	p					Residential area
257	259	739,755	2,892,735	SE	SE	17	Crawfish	2-5	0.007	p		p			Residential area, adjacent to D Road
258	260	739,818	2,892,909	NE	SE	17	Big Chief	5-10	0.030	p		p			Residential area, under Picher Road, adjacent to D Road
259	261	739,811	2,893,225	NE	SE	17	Big Chief	< 2	0.002	p		p			Residential area, adjacent to D Road
260	262	740,034	2,893,279	NE	SE	17	Big Chief	> 50	0.071	p		p			Residential area, under Main Road
261	263	740,010	2,893,575	NE	SE	17	Big Chief	5-10	0.009	p		p			Residential area, adjacent to Columbus Road
262	264	740,072	2,893,762	NE	SE	17	Big Chief	10-25	0.011	p		p	p		Residential area, adjacent to Hwy 69
263	265	740,164	2,893,759	NE	SE	17	Big Chief	10-25	0.115	p		p	p		Residential area, adjacent to Hwy 69
264	266	740,291	2,893,588	NE	SE	17	Big Chief	> 50	0.395	p		p	p		Residential area, adjacent to Hwy 69
265	267	740,439	2,893,611	NE	SE	17	Big Chief	5-10	0.018						Pasture
266	268	740,619	2,893,642	NE	SE	17	Big Chief	5-10	0.011	p					Residential area
267	269	740,613	2,893,240	NE	SE	17	Big Chief	5-10	0.011						Pasture and Mine waste
268	270	740,727	2,893,509	NE	SE	17	Big Chief	5-10	0.009	p		p			Residential area
269	271	740,798	2,893,313	NE	SE	17	Big Chief	< 2	0.002			p			Pasture mine waste
270	272	740,872	2,893,313	NE	SE	17	Big Chief	< 2	0.002			p			Adjacent to Road F
271	273	740,855	2,893,440	NE	SE	17	Big Chief	10-25	0.002			p			Under Road F
272	274	740,922	2,893,327	NE	SE	17	Big Chief	10-25	0.011			p			Adjacent to Road F
273	275	741,483	2,893,766	SE	NE	17	Goodwin	10-25	0.062			p	p		Pasture, adjacent to Hwy 69
274	276	741,202	2,893,377	NE	SE	17	Big Chief	25-50	0.386	p		p			Residential area
275	277	741,062	2,892,918	NE	SE	17	Big Chief	2-5	0.007	p		p			Residential area, adjacent to Picher Road
276	278	741,340	2,892,796	SE	NE	17	Goodwin	2-5	0.002	p		p			Residential area, under Pitcher Road
277	279	741,476	2,892,762	SE	NE	17	Goodwin	5-10	0.032	p		p			Residential area
278	280	741,772	2,892,651	SE	NE	17	Goodwin	5-10	0.039			p			Under Netta Road
279	281	742,068	2,892,861	SE	NE	17	Goodwin	2-5	0.048						Pasture - Mine waste
280	282	742,059	2,893,669	SE	NE	17	Goodwin	5-10	0.037			p	p		Pasture, adjacent to Hwy 69
281	283	742,281	2,893,488	SE	NE	17	Goodwin	10-25	0.282						Pasture - Mine waste
282	284	742,439	2,892,648	SE	NE	17	Goodwin	5-10	0.225			p			Wooded, under Netta Road
283	285	735,578	2,893,943	NE	SE	20	Premier	< 2	0.018			p	p		Under Premier Chat Pile, adjacent to Hwy 69
284	286	734,691	2,894,058	SE	SE	21	Premier	2-5	0.090			p	p		Under Premier Chat Pile, adjacent to Hwy 69
285	287	735,392	2,889,284	NW	SW	20	Kenoyer	5-10	0.085					r	Under Kenoyer Chat Pile, adjacent Access Road
286	288	734,666	2,889,019	SE	SW	20	Kenoyer	10-25	0.163					r	Under Kenoyer Chat Pile, adjacent Road 570
							Total Acreage of Estimated Subsidence		87.68						

TABLE 7.3
EVALUATION OF SUBSIDENCE POTENTIAL AT AREAS IDENTIFIED BY RETIRED MINERS IN CY2000

ID	IDENTIFYING COMMENT	INTEPRETED LOCATION				Subsidence Estimate
		1/4, 1/4 Section	1/4 Section	Section	Lease	
1	Tribune newspaper office, Picher-behind office, major underground rock fall goes back to the ball field; west edge of ball field there is a shaft that was filled with wood ties only, then filled with dirt.	NE	NE	20	Netta East	No potential subsidence calculated, primarily due to minimal working height, 43 percent of pillars removed and 23 percent trimmed in this area (see Appendix A).
2	Black Hawk-pillars shot away in later years. Pull drift leading west to R. Harrell park under which there is an unsupported cavern that the Astrodome would fit into.	NE	SE	20	St. Joe	Up to 50 ft of subsidence possible. Significant potential subsidence area located under St. Joe chat pile.
3	Center field area of old tristate miners ball park-large underground rock fall, roof height 100 ft. plus.	NE	SE	20	Premier	No potential subsidence calculated.
4	John Beaver-Crystal-Ritz-up to Velie Lion-all this workings mined to very high roof, sheet ground (shale) unstable plus lower strata made unstable by tar seams.	NE and NW	SE	19	John Beaver	Up to 50 ft of subsidence possible.
		SE	SW	19	Crystal	Back-Analysis Case study, not in study area.
		NE	NW	30	Ritz	
5	Lucky Syndicate-north of pits toward Treece, east of Tar Creek-very bad ground with very thin or no upper limestone supporting strata.	SW	NW	17	Lucky Syndicate	Not in study area
6	Piokee and later Dew Drop mine shaft-removed pillars in later years; a cave-in of east side of Piokee.	SE	SW	17	Piokee	Up to 25 ft of subsidence possible.
7	Lucky Bill to Rialto #1 and #2 - pillars removed and totally mined out. Especially around shafts for a 200 ft radius. The roof gets higher toward the Admiralty Mine where it was necessary to drill from 75 ft high tower to reach the mine working face.	NE	NE	30	Lucky Bill	5 to 10 ft of subsidence possible.
8	Humble gravel plant-area under chat pile which includes the Rialto mill shaft lacks support due to absence of supporting limestone, and was mined up to the shale in many areas. Reported early years cave-in south side of chat pile close to old Hwy 69 which filled itself with chat from the tailings pile.	NE	NW	29	Rialto	Up to 50 ft of subsidence possible.
		SE	SW	20	Rialto	Up to 25 ft of subsidence possible.
9	Admiralty #1 and #3-unusual geological feature: Miami fault line and anticline visible in the mine; faults known to be prone to slippage.				Admiralty No. 1	Not in study area
		SW	SE	29	Admiralty No. 3	Back-Analysis Case study, not in study area.
10 & 11	Beck, southward across east A Street to Hudson mine; cave-in on north side of road, connected underground to location where A Street caved-in to the East.	SE and SW	SW	15	Beck	5 to 10 ft of subsidence possible.
12	West of Blue Goose #2 - caved-in through chat pile years ago, workings unstable and had many roof slab falls during operating years.	SE and NE	SW	30	Blue Goose 2	Existing collapse feature, model indicates up to 50 ft of subsidence possible.
13	Goodeagle - although not connected underground to other workings, was mined out on multiple levels to a very high roof.				Goodeagle	Not in study area
14	Bendalari and Cherokee - these are in Kansas and had very unstable workings. Former shaft was recribbed 5 times due to poor stability. Typical of mines in the Treece, KS area.					Not in study area
15	Federal - West of Lucky Syndicate - same comments as Lucky Syndicate.					Not in study area

TABLE 7.3 (Continued) EVALUATION OF SUBSIDENCE POTENTIAL AT AREAS IDENTIFIED BY RETIRED MINERS IN CY2000						
		INTEPRETED LOCATION				
ID	IDENTIFYING COMMENT	1/4, 1/4 Section	1/4 Section	Section	Lease	Subsidence Estimate
16	Howe - West side of tar creek and west of Piokee; had very thin upper strata of limestone, poses threat to Tar Creek if it subsides.	SW	SW	17	Howe	Existing non-shaft related collapse.
17	New ball park, east edge of street; improperly filled shaft over cavernous area unsupported by pillars.	NW	NE	20	Netta West	Unable to identify shaft. No expression of subsidence calculated in that immediate area.
18	Davis Big Chief & Davis White (later Otis White) - this workings northward and to the southwest was unstable due to tar seams and deposits all the way up to the "E" member of the Boone Formation.	NE	SE	17	Big Chief	Up to 50 ft of subsidence possible.
					Otis White	Not in study area
19	Emma Gordon Mine in Commerce area was in very narrow drifts due to nature of ore deposits and lack of good rock overhead for roof support. Room and pillar method less used here.					Not in study area - Located west of Commerce.
20	Cactus to Jones & Goldberg - there is a shaft between these two mines not shown on map, right on the section line. Mined area quite shallow and not in stable rock formations probably accounting for present cave-ins.					Not in study area - Located west of Commerce.

7.6 IMPLICATIONS OF STUDY RESULTS FOR PUBLIC SAFETY IN THE STUDY AREA

All mined areas are prone to subsidence, and the Picher Mining Field is no exception. As indicated in Section 1.1.1, the safety implications of subsidence are a valid concern for residents. Past subsidence events in the Picher Mining Field and their impacts on the citizens are not well documented. However, several incidents of residents falling into open mine shafts, multiple collapses occurring in residential areas involving both houses and residents, and numerous accidents, injuries, and even deaths affecting residents and visitors have been reported, and a few of these documented. Along with existing collapses, which tend to increase in size over time with erosion and additional collapse, new collapse features continue to be discovered. Open shafts or collapses with steep sides can make escape difficult, thereby compounding the safety hazard. Improperly filled collapses and mine shafts that now may be hidden can often re-collapse, causing a new hazard. Both the Eagle-Picher Mining Company and the BIA have in the past initiated actions to restrict land use in areas that they determined were a hazard to residents. Locations previously restricted are described in Section 1.1.3.

Shaft related and non-shaft related subsidence events have occurred in the Picher Mining Field since the beginning of mining operations and, based on the results of this study, will continue to occur.

7.7 IMPLICATIONS OF STUDY RESULTS FOR THE LOCAL ENVIRONMENT

As noted in Section 1.1.2, there are several environmental issues associated with subsidence in the study area: surface runoff into subsidence sites, non-engineered modification of drainage systems, water quality degradation, and the illegal dumping of commercial and residential waste in the subsidence sites. Surface runoff has been a problem dating back to the beginning of mining at the Picher Mining Field. Due to the relatively flat topography of the area, heavy rains often plagued the mining companies by creating large amounts of surface runoff that found its way to open mine shafts and flooded the mine workings. As the mines were abandoned and subsidence events occurred, surface runoff began to fill the mines and the larger subsidence features.

A 15-month field evaluation of mine shafts and subsidence features at the 43-square-mile Tar Creek site was conducted in 2004–2005 by OGS (Luza and Keheley, 2005: personal communication). One noticeable aspect of the evaluation was the extensive amount of commercial and residential waste found in open mine shafts and shaft related and non-shaft related subsidence features. Examples include animal carcasses, chemicals, human waste, tires, construction materials, and motor oil. It was noted that many of the open mine shafts on private land are being used as waste dumps. Most of the open mine shafts are partially filled with water. The overall effect on water quality from waste disposal in the mining field has not been evaluated.

There are several new environmental consequences potentially associated with subsidence in the study area:

- Although not explicitly evaluated, it is likely that there will be damage to powerlines, pipelines and sewer lines within residential areas.
- A sewage lagoon for the town of Cardin was constructed over an abandoned mine shaft of unknown integrity and is therefore subject to subsidence.
- Potential subsidence areas 167 and 169 (identified in Exhibit 21) are under and adjacent to the Picher sewage lagoons, respectively.
- Potential subsidence areas 83 and 85 (identified in Exhibit 29) are under and adjacent to the Cardin sewage lagoons, respectively.
- There may be environmental impacts associated with the transport of dangerous loads where road and/or rail lines are subject to subsidence.

7.8 IMPLICATIONS OF STUDY RESULTS ON CURRENT AND FUTURE LAND USE

As indicated in Section 1.1.3, the determination of appropriate land use in the Picher Mining Field is partially dependent on the long term stability of the land underlain by mine workings. Uncertainty regarding the location and extent of the underground mine workings, as well as stability concerns, have previously hindered residential and business development. This report provides new information on the location and extent of the underground mine workings and the potential for subsidence and mine shaft failures. Unfortunately, the new information will have the direct result of further devaluating some of the property already devalued in the past 25 years.

For this subsidence evaluation to be of value, it must result in rethinking the approach for addressing hazards and risks in the mining field. The field can no longer be viewed as a Superfund site where residential lead exposure and mill tailings are the only primary hazards being addressed. There must be a refocused effort to evaluate subsidence and Superfund issues jointly to determine the appropriate uses of the impacted land. With the increased knowledge gained from the subsidence evaluation, it is reasonable to question and reevaluate the assumption that all parts of the field are appropriate for development if the ground surface is remediated or reclaimed. As a first step of the reevaluation, only those impacted areas having the potential for safe use with regard to subsidence should be reclaimed on a priority basis to make effective use of limited resources. The severely impacted areas not appropriate for residential and/or business development should be identified and given a lower priority. It may also be appropriate to leave some minimally impacted areas in their present condition.

There are also potential issues with existing housing and future construction in the mining field. U.S. Housing and Urban Development Agency (HUD) regulations provide requirements for evaluating the habitability of existing federal housing and the siting of prospective building sites. HUD Directives Nos. 4905.1 and 4910.1 describe the hazards, including subsidence, that must be evaluated. Additionally, HUD Builders Certification HUD – 92451 (4/2001) requires builders to certify if prospective building sites are located on the EPA Superfund (NPL) list or equivalent state list. If the proposed construction is to be located in a Superfund site, a copy of a state licensed engineer (soils and structural) reports, designs, and certifications showing compliance with HUD requirements to ensure the structural soundness of the improvements and the health and safety of the occupants is required.

HUD also requires lending institutions to certify (Form HUD-92564-VC) if there is evidence of subsidence in the area where the structure is to be built as a condition for providing federally insured construction funds. HUD also requires lending institutions to certify hazards that endanger the health and safety of the occupants and/or the marketability of the property. There are examples in the Picher area where prospective buyers have been refused federally insured loans as a result of the properties being located within the Superfund site.

Some existing houses in the Picher area most likely do not meet the HUD requirements for habitability or for financing home improvements or sales. Future construction of homes and other structures may also be at risk due to the certifications required by the builders and lenders.

The maps and exhibits contained in this report are intended to provide developers, lenders and land use managers with basic information on the locations of mine workings and their potential impacts for subsidence and mine shaft failure. The report is also intended to serve as a guide to determine the need to conduct investigations prior to siting and constructing new facilities.

7.9 SECTION 7 REFERENCES

Luza, 2005, personal communication.

Luza and Keheley, 2005, personal communication.

McKnight, E. T.; and Fischer, R. P., 1970, Geology and ore deposits of the Picher field, Oklahoma and Kansas: U.S. Geological Survey Professional Paper 588, p. 165.

Table 7.4 Summary of Areas, Location, Range of Potential Subsidence, and Probability of Subsidence Areas																
Count	ID	Northing	Easting	Quarter, Quarter Section	Quarter Section	Section	Mine Lease	Estimated Maximum Subsidence (feet)	Maximum Probability of Subsidence (%)	Estimated Area (ac)	Residences or Structures	Public/School Parks and Playgrounds	City Streets and Major Transportation Corridors within Municipal Boundaries	Major Transportation Corridors	Rural Roads	Affected Feature
											p = Picher, c = Cardin, h = Hockerville, rs = rural structure, rtc = rural transportation corridor, r = rural road, rail = railroad					
1	0	724,251	2,894,732	NW	SW	33	John Hunt	10-25	< 20	0.172				rtc		East of Hwy 69 in field
2	5	726,248	2,894,958	SW	NW	33	Craig	10-25	< 20	0.112					r	Pasture Land
3	7	726,415	2,895,445	SW	NW	33	Craig	25-50	< 20	1.095					r	Pasture Land
4	8	726,966	2,894,715	NW	NW	33	Craig	5-10	< 20	0.280				rtc		Adjacent to Hwy 69, Pasture Land
5	10	727,658	2,894,645	NW	NW	33	Craig	25-50	20-50	1.219				rtc		Adjacent to Hwy 69
6	11	727,815	2,895,229	NW	NW	33	Craig	> 50	> 50	0.399					r	South of 40 Road - Pasture Land
7	12	728,092	2,895,361	NW	NW	33	Craig	10-25	< 20	0.034					r	North of 40 Road - Pasture Land
8	13	730,202	2,909,203	NE	SE	26	Alice Greenback	10-25	< 20	0.066				rtc		Under Hwy 69 (Alt)
9	21	732,031	2,894,493	NW	NW	28	Birthday	> 50	> 50	5.085				rtc		Indtrial area, Under Hwy 69
10	25	730,779	2,894,461	SW	NW	28	Federal-Fort Worth	10-25	< 20	0.085				rtc		Adjacent to Hwy 69 - Pasture Land
11	35	729,245	2,894,427	NW	SW	28	Skelton	10-25	> 50	0.053				rtc		Adjacent to Hwy 69 - In flotation pond
12	39	728,635	2,894,484	SW	SW	28	Skelton	< 2	< 20	0.053				rtc		Wooded
13	41	728,388	2,894,443	SW	SW	28	Skelton	2-5	< 20	0.005				rtc		Adjacent to Hwy 69
14	42	728,204	2,894,527	SW	SW	28	Skelton	25-50	> 50	0.583				rtc		Near residence, adjacent to Hwy 69
15	43	727,865	2,893,998	NE	NE	32	Beck	2-5	< 20	0.184	rs				r	Residential area, adjacent to 40 Road
16	44	728,396	2,894,285	SE	SE	29	Skelton	5-10	< 20	0.005				rtc		Adjacent to Hwy 69, Mine waste area
17	45	728,153	2,893,434	SE	SE	29	Skelton	25-50	< 20	0.191					r	Under Chat pile, North of 40 Road
18	46	728,875	2,894,183	SE	SE	29	Skelton	25-50	< 20	1.933				rtc		Under and adjacent to Hwy 69
19	55	729,499	2,894,289	SE	SE	29	Skelton	< 2	< 20	0.011				rtc		Adjacent to Hwy 69
20	57	730,008	2,894,227	NE	SE	29	Skelton	10-25	< 20	0.007				rtc		Adjacent to Hwy 69
21	59	730,278	2,894,205	NE	SE	29	Skelton	25-50	< 20	0.158				rtc		Adjacent to Hwy 69
22	64	731,096	2,893,999	SE	NE	29	Skelton	10-25	< 20	0.021	rs					Commercial Building
23	71	732,954	2,893,175	NE	NE	29	Barbara J.	10-25	< 20	0.331					r	Adjacent to 12th st., south side
24	81	732,915	2,891,336	NE	NW	29	Rialto	10-25	< 20	1.398				rtc		Adjacent to 30 Road (Cardin Road)
25	84	733,042	2,890,538	NE	NW	29	Rialto	2-5	< 20	0.067				rtc		Adjacent to 30 Road (Cardin Road)
26	85	732,672	2,890,103	NW	NW	29	Baby Jim	25-50	< 20	1.956				rtc		Adjacent to Cardin Rd
27	87	732,745	2,889,133	NW	NW	29	Baby Jim	> 50	> 50	2.750	c		c	c		Residential area, under 1st st., adjacent to Tar River st.
28	89	727,260	2,884,712	NW	NW	31	Southside	5-10	< 20	0.014				rtc		Adjacent to Cardin Road
29	90	727,422	2,884,645	NW	NW	31	Southside	10-25	< 20	0.067				rtc		Adjacent to 565 Road (Cardin Road)
30	91	727,112	2,883,995	NW	NW	31	Southside	25-50	< 20	0.624					r	Under 560 Road
31	93	729,896	2,886,159	NE	SW	30	Blue Goose No. 2	> 50	< 20	0.739				rtc		Adjacent to 565 Road (Cardin Road)
32	95	730,331	2,885,769	SE	NW	30	HUM-BAH-WAT-TAH	25-50	> 50	2.679				rtc		Under 565 Road (Cardin Road)
33	96	730,902	2,886,226	SE	NW	30	HUM-BAH-WAT-TAH	5-10	< 20	0.207				rtc		Adjacent to 565 Road (Cardin Road)
34	98	730,762	2,886,517	SW	NE	30	Jay Bird	10-25	< 20	1.453	rs			rtc		Residential Area, adjacent to 565Road (Cardin Road)
35	107	732,931	2,888,354	NE	NE	30	Lucky Bill	5-10	< 20	0.112	c		c	c		Residential area, adjacent to 1st st./Cardin Rd.
36	108	732,870	2,887,672	NW	NE	30	Bennie	2-5	< 20	0.060	c		c	c		Residential area, adjacent to 1st st./Cardin Rd.
37	109	732,330	2,887,377	NW	NE	30	Bennie	2-5	< 20	0.149	rs					Residential area
38	110	732,599	2,886,977	NW	NE	30	Bennie	10-25	< 20	0.397	c		c	c		Residential area, under 565 Road/Cardin Rd.
39	111	731,729	2,886,639	NW	NE	30	Bennie	> 50	< 20	0.838				rtc		Under 565 Road/Cardin Rd
40	113	732,752	2,885,427	NE	NW	30	Ritz	2-5	> 50	0.048					r	Adjacent to East 30 Road
41	116	733,399	2,888,249	SE	SE	19	Townsite	10-25	< 20	0.475	c		c			Residential area, under 2nd and Main streets
42	132	735,094	2,888,842	NE	SE	19	John Beaver	2-5	< 20	0.126	rs				r	Near residence, adjacent to River Road
43	133	737,235	2,889,068	NW	NW	20	Dorothy Bill No. 2	5-10	< 20	0.443	rs				r	Near residence, adjacent to River Road
44	134	737,840	2,889,037	NW	NW	20	Dorothy Bill No. 2	25-50	< 20	0.096					r	Adjacent to a non-shaft related collapse
45	135	738,296	2,889,707	NW	NW	20	Dorothy Bill No. 2	5-10	< 20	0.064				rtc		Adjacent to 20 Road
46	137	736,756	2,891,487	SW	NE	20	Vantage	5-10	< 20	0.011	p		p			Residential area, under College Road
47	138	737,157	2,891,235	NE	NW	20	Dorothy Bill No. 2	10-25	< 20	0.847	p		p			Residential area, under Cherokee and 3rd streets
48	139	737,856	2,891,839	NW	NE	20	West Netta	25-50	20-50	0.634	p	p	p			Residential and School playground area, under Frisco st.
49	140	737,500	2,893,361	NE	NE	20	East Netta	> 50	> 50	1.600	p	p	p			Reunion Park and Residential Area, under Main and 2nd st.
50	141	737,476	2,892,638	NW	NE	20	West Netta	25-50	> 50	0.491	p	p	p			Residential area, under 2nd st., soccer field
51	142	736,728	2,892,709	SW	NE	20	Vantage	> 50	20-50	1.139	p		p			Under Vantage Chat Pile, Residential area, under 4th st., adjacent to Netta st.
52	143	736,931	2,892,482	SW	NE	20	Vantage	5-10	< 20	0.055			p			Under Vantage Chat Pile
53	144	736,548	2,892,210	SW	NE	20	Vantage	2-5	< 20	0.014			p			Wooded

Table 7.4
Summary of Areas, Location, Range of Potential Subsidence, and Probability of Subsidence Areas

Count	ID	Northing	Easting	Quarter, Quarter Section	Quarter Section	Section	Mine Lease	Estimated Maximum Subsidence (feet)	Maximum Probability of Subsidence (%)	Estimated Area (ac)	Residences or Structures	Public/School Parks and Playgrounds	City Streets and Major Transportation Corridors within Municipal Boundaries	Major Transportation Corridors	Rural Roads	Affected Feature
											p = Picher, c = Cardin, h = Hockerville, rs = rural structure, rtc = rural transportation corridor, r = rural road, rail = railroad					
54	152	735,411	2,891,240	NE	SW	20	Kenoyer	5-10	< 20	0.055	p		p			Residential area, under 6th st., adjacent to Cherokee st.
55	153	734,353	2,891,023	SE	SW	20	Rialto	5-10	< 20	2.284	p		p			Extensive area, Residential area, under Ottawa Road
56	156	733,275	2,891,400	SE	SW	20	Rialto	5-10	< 20	0.241			p	p		Adjacent to 30 Road (Cardin Road) and College st.
57	159	733,385	2,892,262	SW	SE	20	Barbara J	25-50	< 20	0.354			p	p		Adjacent to Cardin Road/Under Barbara J Chat Pile
58	160	733,269	2,893,476	SE	SE	20	Oko	25-50	< 20	0.073			p			In Lytle Creek, adjacent to 12th st.and OKO Chat Pile
59	163	734,192	2,893,922	SE	SE	20	Oko	5-10	< 20	0.006	p					Residential Area
60	165	734,378	2,893,645	SE	SE	20	Oko	5-10	< 20	0.018	p		p	p		Under Cardin Road, Residential Area
61	166	734,682	2,893,673	NE	SE	20	Premier	10-25	< 20	0.769	p		p	p		Residential area, adjacent to Main and Cardin streets
62	171	733,611	2,896,175	SE	SW	21	Grace Walker	10-25	< 20	0.331	p		p			Residential area, near 11th street
63	172	733,478	2,894,906	SW	SW	21	New York	25-50	< 20	0.941	p		p			Residential area, adjacent to 12th st.
64	173	733,777	2,895,496	SE	SW	21	Grace Walker	2-5	< 20	0.011	p		p			Residential area, adjacent to Ella St
65	176	734,213	2,895,713	SE	SW	21	Grace Walker	2-5	< 20	0.007	p		p			Residential area, adjacent to 9th St
66	179	734,340	2,895,763	SE	SW	21	Grace Walker	5-10	< 20	0.014	p		p			Residential area, north of 9th St
67	182	734,920	2,895,030	NW	SW	21	Black Hawk	< 2	< 20	0.009	p		p			Residential Area, adjacent to 7th St
68	183	735,023	2,894,418	NW	SW	21	Black Hawk	5-10	< 20	0.009	p		p			Residential area, under Francis St
69	184	735,460	2,894,320	NW	SW	21	Black Hawk	< 2	< 20	0.005	p		p			Residential area, adjacent to 6th St
70	185	735,826	2,895,142	NW	SW	21	Black Hawk	10-25	< 20	0.055	p		p			Residential area, near intersection of Ethel and 5th streets
71	191	737,571	2,899,405	NE	NE	22	Indiana	5-10	< 20	0.333					r	Adjacent to Road 590
72	193	738,087	2,904,551	NE	NE	22	Indiana	< 2	< 20	0.011					r	Wooded and Pasture, adjacent to Road 600
73	196	738,737	2,908,540	NW	NE	23	Aztec	> 50	< 20	0.363	rs			rtc		Residences nearby, adjacent to A st.
74	197	737,774	2,912,725	SW	NE	24	St. Louis No. 4	25-50	< 20	0.080				rail		Adjacent to RR tracks
75	198	737,965	2,913,097	NW	NE	24	St. Louis No. 4	10-25	< 20	0.041				rail		Adjacnet toRailroad, Pasture and Wooded
76	199	738,317	2,913,265	NW	NE	24	St. Louis No. 4	25-50	< 20	0.161				rail		Adjacent to RR tracks
77	202	738,165	2,918,416	NW	NE	19R24	Malsbury	25-50	< 20	0.069				rtc		Large area extending under Hwy 69A
78	207	743,035	2,908,780	SE	NE	14	Farmington	10-25	< 20	0.099			h			Adjacent to State Line Road, under mine waste
79	212	742,323	2,907,608	SE	NE	14	Farmington	> 50	> 50	2.222	h		h			Existing collapse, adjacent to residence
80	213	741,742	2,907,554	NW	SE	14	Lucky Jenny	10-25	< 20	0.101	h					Residential area
81	214	742,046	2,908,152	SE	NE	14	Farmington	25-50	20-50	0.310	h					Residential area
82	215	741,733	2,908,613	NE	SE	14	Lucky Jenny	10-25	< 20	0.005			h			Under dirt Road 013, close to residential
83	217	738,995	2,906,571	SE	SW	14	Dobson	2-5	< 20	0.028				rtc		Existing collapse, adjacent to East 20 Road/A St
84	218	740,394	2,908,673	NE	SE	14	Lucky Jenny	5-10	< 20	0.002	h					Pasture, near residence
85	219	740,479	2,908,405	NW	SE	14	Lucky Jenny	< 2	< 20	0.002			h			Wooded, near mine waste
86	220	739,841	2,908,316	SE	SE	14	Niday No. 1	10-25	< 20	0.067	h		h			Under Residence near Road 606
87	221	740,446	2,907,769	NW	SE	14	Lucky Jenny	10-25	< 20	0.631			h			Pasture, under dirt Road 605
88	222	740,704	2,907,441	NW	SE	14	Lucky Jenny	25-50	< 20	0.145			h			Near residence, under dirt Road 604
89	224	739,927	2,904,663	SE	SW	14	Dobson	< 2	< 20	0.007					r	Pasture, adjacent to dirt Road 600
90	227	739,655	2,894,271	SE	SW	16	Eudora Whitebird	10-25	< 20	0.126	p		p			Residential area, under to Francis Road
91	228	740,403	2,894,299	NW	SW	16	Commonwealth	2-5	< 20	0.007	p		p			Residential area
92	229	741,169	2,894,687	NW	SW	16	Commonwealth	< 2	< 20	0.099	p		p			Residential area, adjacent to Alta Road
93	230	741,469	2,894,024	SE	NW	16	Swift	2-5	< 20	0.050	p		p	p		Residential area, adjacent to Hwy 69
94	231	742,696	2,893,963	SW	NW	16	Swift	< 2	< 20	0.009	p		p	p		Residential area, near intersection of Hwy 69 and A st.
95	232	738,522	2,892,104	SW	SE	17	Netta White	10-25	< 20	0.057	p		p			Residential area, under Vantage Road
96	233	738,685	2,892,476	SW	SE	17	Netta White	< 2	< 20	0.016	p		p			Residential area
97	234	738,802	2,892,127	SW	SE	17	Netta White	10-25	< 20	0.165	p		p			Residential area, under Vantage Road
98	242	739,528	2,890,689	SE	SW	17	Piokee	10-25	< 20	0.101			p			Adjacent to Ottawa Road, mine waste
99	243	739,595	2,890,458	SE	SW	17	Piokee	5-10	< 20	0.030			p			Under Ottawa Road, mine waste
100	246	738,918	2,891,530	SW	SE	17	Netta White	25-50	> 50	3.471	p					Residential Area, existing collapse feature
101	252	740,617	2,892,706	NE	SE	17	Big Chief	10-25	< 20	0.032	p		p			Residential Area
102	253	740,209	2,892,583	NW	SE	17	Otis White	2-5	< 20	0.090	p		p			Residential Area, adjacent to Netta Road
103	254	740,059	2,892,421	NW	SE	17	Otis White	2-5	< 20	0.016	p					Wooded area adjacent to Ottawa Chat Pile
104	255	739,460	2,892,377	SW	SE	17	Netta White	25-50	< 20	0.411	p		p			Near residential area

Table 7.4 Summary of Areas, Location, Range of Potential Subsidence, and Probability of Subsidence Areas																
Count	ID	Northing	Easting	Quarter, Quarter Section	Quarter Section	Section	Mine Lease	Estimated Maximum Subsidence (feet)	Maximum Probability of Subsidence (%)	Estimated Area (ac)	Residences or Structures	Public/School Parks and Playgrounds	City Streets and Major Transportation Corridors within Municipal Boundaries	Major Transportation Corridors	Rural Roads	Affected Feature
											p = Picher, c = Cardin, h = Hockerville, rs = rural structure, rt = rural transportation corridor, r = rural road, rail = railroad					
105	256	739,476	2,892,720	SW	SE	17	Netta White	10-25	< 20	0.037	p		p			Residential Area, adjacent to Netta Road
106	257	739,681	2,893,218	SE	SE	17	Crawfish	10-25	< 20	0.051	p		p			Residential area
107	258	739,622	2,892,875	SE	SE	17	Crawfish	2-5	< 20	0.051	p					Residential area
108	259	739,755	2,892,735	SE	SE	17	Crawfish	2-5	< 20	0.007	p		p			Residential Area, adjacent to D Road
109	260	739,818	2,892,909	NE	SE	17	Big Chief	5-10	< 20	0.030	p		p			Residential area, under Picher Road, adjacent to D Road
110	261	739,811	2,893,225	NE	SE	17	Big Chief	< 2	< 20	0.002	p		p			Residential area, adjacent to D Road
111	262	740,034	2,893,279	NE	SE	17	Big Chief	> 50	20-50	0.071	p		p			Residential area, under Main Road
112	263	740,010	2,893,575	NE	SE	17	Big Chief	5-10	< 20	0.009	p		p			Residential area, adjacent to Columb Road
113	264	740,072	2,893,762	NE	SE	17	Big Chief	10-25	< 20	0.011	p		p	p		Residential area, adjacent to Hwy 69
114	265	740,164	2,893,759	NE	SE	17	Big Chief	10-25	< 20	0.115	p		p	p		Residential area, adjacent to Hwy 69
115	266	740,291	2,893,588	NE	SE	17	Big Chief	> 50	< 20	0.395	p		p	p		Residential area, adjacent to Hwy 69
116	268	740,619	2,893,642	NE	SE	17	Big Chief	5-10	< 20	0.011	p					Residential area
117	270	740,727	2,893,509	NE	SE	17	Big Chief	5-10	< 20	0.009	p		p			Residential Area
118	271	740,798	2,893,313	NE	SE	17	Big Chief	< 2	< 20	0.002			p			Pasture maine waste
119	272	740,872	2,893,313	NE	SE	17	Big Chief	< 2	< 20	0.002			p			Adjacent to Road F
120	273	740,855	2,893,440	NE	SE	17	Big Chief	10-25	< 20	0.002			p			Under Road F
121	274	740,922	2,893,327	NE	SE	17	Big Chief	10-25	< 20	0.011			p			Adjacent to Road F
122	275	741,483	2,893,766	SE	NE	17	Goodwin	10-25	< 20	0.062			p	p		Pasture, adjacent to Hwy 69
123	276	741,202	2,893,377	NE	SE	17	Big Chief	25-50	< 20	0.386	p		p			Residential Area
124	277	741,062	2,892,918	NE	SE	17	Big Chief	2-5	< 20	0.007	p		p			Residential area, adjacent to Picher Road
125	278	741,340	2,892,796	SE	NE	17	Goodwin	2-5	< 20	0.002	p		p			Residential Area, under Pitcher Road
126	279	741,476	2,892,762	SE	NE	17	Goodwin	5-10	< 20	0.032	p		p			Residential area
127	280	741,772	2,892,651	SE	NE	17	Goodwin	5-10	< 20	0.039			p			Under Netta Road
128	282	742,059	2,893,669	SE	NE	17	Goodwin	5-10	< 20	0.037			p	p		Pasture, adjacent to Hwy 69
129	284	742,439	2,892,648	SE	NE	17	Goodwin	5-10	< 20	0.225			p			Wooded, under Netta Road
130	285	735,578	2,893,943	NE	SE	20	Premier	< 2	< 20	0.018			p	p		Under Premier Chat Pile, adjacent to Hwy 69
131	286	734,691	2,894,058	SE	SE	21	Premier	2-5	< 20	0.090			p	p		Under Premier Chat Pile, adjacent to Hwy 69
132	287	735,392	2,889,284	NW	SW	20	Kenoyer	5-10	< 20	0.085					r	Under Kenoyer Chat Pile, adjacent Access Road
133	288	734,666	2,889,019	SE	SW	20	Kenoyer	10-25	< 20	0.163					r	Under Kenoyer Chat Pile, adjacent Road 570

Insert Figure 7.1, *Insert Netta West Cross Sections*

Insert Figure 7.2, *Overview of Locations for Estimated Maximum Subsidence*

Insert Figure 7.3A, *Overview of Locations Analyzed for Probability of Subsidence*

Insert Figure 7.3B, *Probability of Subsidence: Section 20, Township 29N, Range 23*

Insert Figure 7.3C, *Probability of Subsidence: Sections 14 and 23, Township 29N, Range 23E*

Insert Figure 7.3D, *Probability of Subsidence: Sections 16 and 17, Township 29N, Range 23E*

Insert Figure 7.3E, *Probability of Subsidence: Sections 19 and 30, Township 29N, Range 23E*

Insert Figure 7.3F, *Probability of Subsidence: Section 21, Township 29N, Range 23E*

Insert Figure 7.3G, *Probability of Subsidence: Section 24, Township 29N, Range 23E and Section 19, Township 29N, Range 24E*

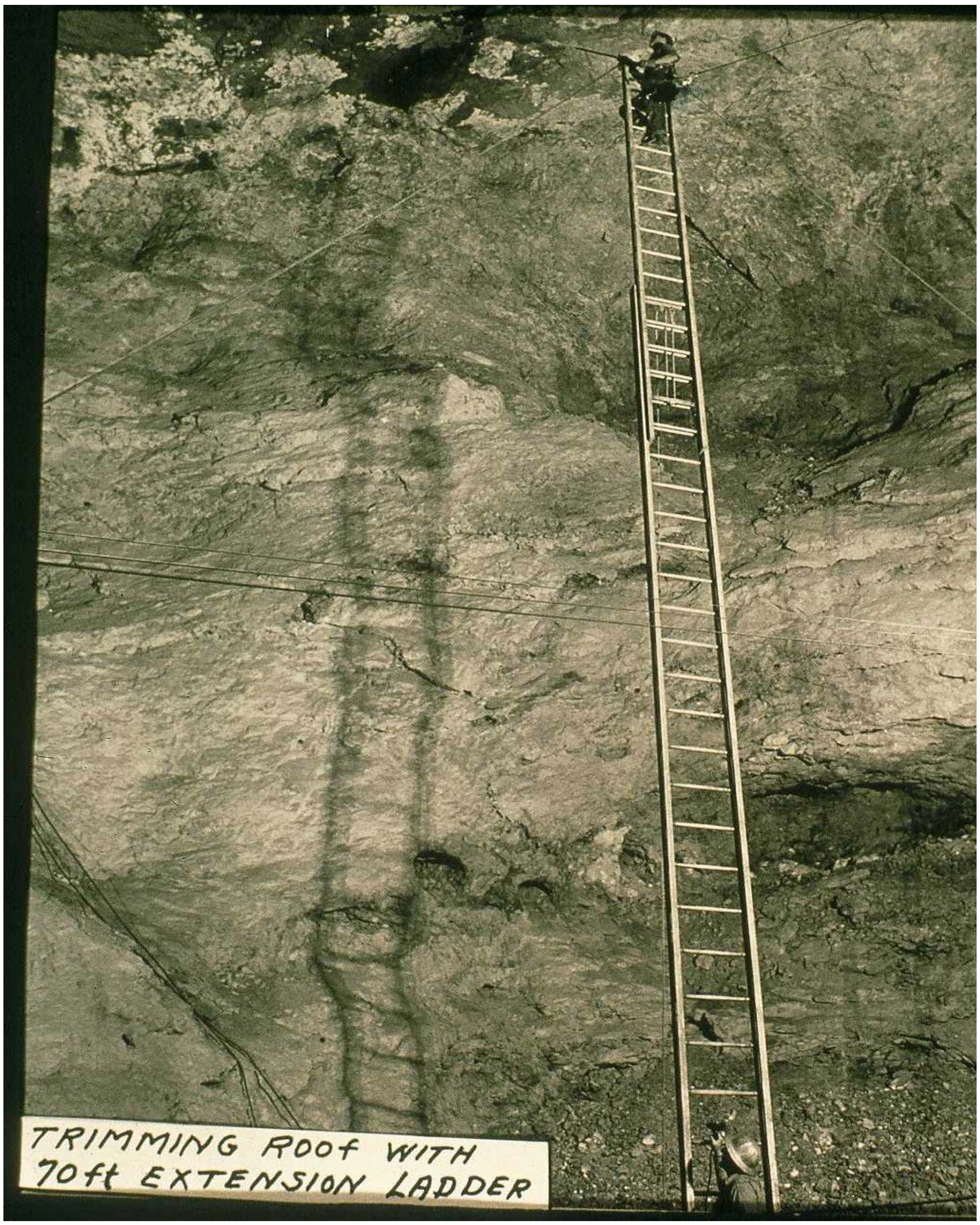
Insert Figure 7.3H, *Probability of Subsidence: Section 26, Township 29N, Range 23E*

Insert Figure 7.3I, *Probability of Subsidence: Sections 28 and 29, Township 29N, Range 23E*

Insert Figure 7.3J , *Probability of Subsidence: Section 31, Township 29N, Range 23E*

Insert Figure 7.3K, *Probability of Subsidence: Sections 32 and 33, Township 29N, Range 23E*

8 Findings and Conclusions



A mine worker (Roof Trimmer) atop a 70 foot extension ladder using a metal bar to remove loose debris from the roof. The Roof Trimmer was the highest paid employee in the underground mines.

8. FINDINGS AND CONCLUSIONS

The process of collecting, evaluating, and interpreting the large amount of map, borehole, and other data and information needed to conduct this subsidence evaluation has resulted in a number of findings and conclusions relative to the evaluation process. These findings are applicable to any future subsidence hazard evaluations, geotechnical investigations, or land use planning that may be conducted within the 4,400-acre study area or the larger Picher Mining District. Analysis of the data to yield estimates of the location and amount of possible subsidence within the study area and to derive a probability of subsidence at a select subset of these locations, has also lead to specific conclusions regarding subsidence and subsidence hazards in the area.

8.1 FINDINGS

- 3,130 acres in the 4,400-acre study area were not undermined. However, 1,270 acres were undermined, of which 88 acres displayed greater than nominal potential for subsidence. The 88 acres found to display greater than nominal potential for subsidence were identified as 286 separate locations and/or clusters.
- Subsidence can occur with little or no advance warning.
- Methodologies are not currently available to accurately predict when subsidence will occur.
- 473 acres of the 1,390 acres of the town of Picher that are located within the study area are undermined.
- 17 acres of the 58 acres of the town of Cardin that are located within the study area are undermined.
- 25 acres of the 231 acres of the town of Hockerville that are located within the study area are undermined.
- The Subsidence Evaluation Team located no maps of mines in the vicinity of the town of Quapaw, and as a result, the extent of the undermining of Quapaw is unknown. The presence of mine shafts and mill sites in the area, however, indicates that significant mining may have occurred beneath the town.
- 4.5 miles of the 19 miles of major transportation corridors in the study area are undermined.
- 15 shaft related and 20 non-shaft related subsidences have occurred in the study area since the 1982 inventory by OGS.
- Factors identified as contributing most to non-shaft related subsidence are width of stope, height of stope, combined thickness of the Boone Formation and Chester above the stope, and depth of stope.
- Current groundwater levels in the study area provide a buoyant effect that reduces the effective load on remnant pillars and mine roofs and therefore may decrease the potential for subsidence.
- Mine maps are of different vintages and the most recent maps do not always include mine workings shown on older maps. Also, discrepancies exist between mine maps within the same lease.
- Map symbols used to indicate different mine levels can be inconsistent from lease to lease, and in some cases are inconsistent within the same lease.
- Interpretation of mine maps is sometimes difficult in areas of multiple-level mining because of overlapping and/or inconsistent map symbols.
- The mine floor and roof elevations can be estimated by using assay data from exploration borehole logs.

- The geology is variable within short distances, as indicated by the exploration borehole logs and available published reports.
- The extraction ratio for many of the mines, calculated from the detailed mine maps, is greater than 90%.
- There is very little existing geotechnical or rock mechanical data to assess the probability of subsidence using available analytical methods.
- There is very little documentation available regarding the shaving and removal of pillars, except for a few isolated cases.
- Details of the mechanics of non-shaft related subsidence in the study area are poorly understood.
- Post-mining subsidence features (post-1970) in the Picher Mining Field have tended to be smaller in size than previous collapses, perhaps indicating a differing collapse and subsidence mechanism than in the earlier collapses.
- Some existing houses in the Picher area most likely do not meet HUD requirements for habitability or for financing home improvements or sales.
- Some areas in the mining field are not suitable for residential or business development given the safety risks and the cost to mitigate them.

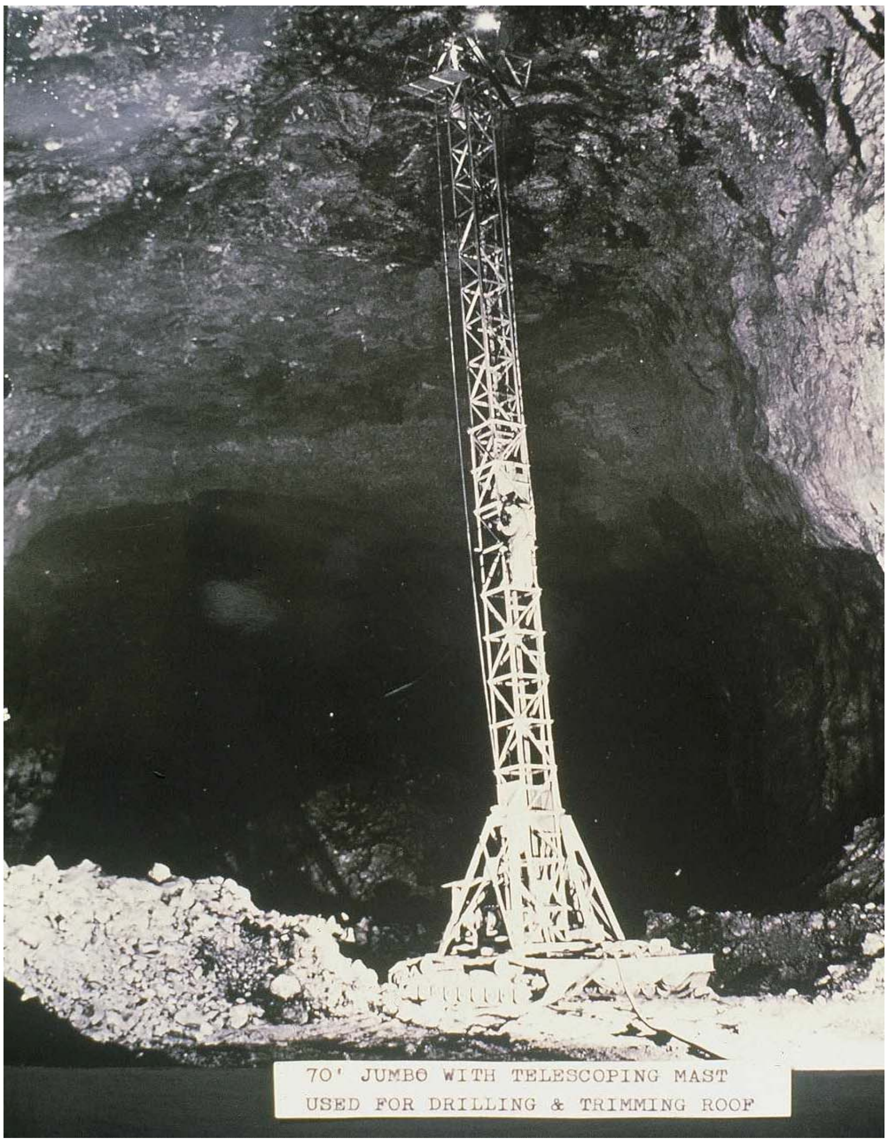
8.2 CONCLUSIONS

The above findings lead to the following conclusions regarding subsidence hazards within the study area:

- The potential for shaft related and non-shaft related subsidence is a very serious threat to the safety and economic well-being of people who reside in and travel through the area.
- The area exposed to subsidence hazards is a relatively small percentage of the total study area, but some residential and public-use areas and portions of transportation corridors are subject to some degree of subsidence hazard.
- 4,312 acres of the 4,400-acre study area are not subject to subsidence based on limited evaluation of available information from mine maps and conservative estimates of rock bulking factors. Further review of all available information may reveal additional areas subject to potential subsidence.
- Based on the back-analysis of failed mine workings, it is probable that additional non-shaft related failures will occur in the future.
- Every shaft has the potential to collapse, and the initial opening of a shaft collapse is likely to be the dimension of the shaft, and may grow as large as 30 feet in diameter.
- The quantifiable variables of 1) width of stope, 2) height of stope, 3) combined thickness of Boone Formation and Chester above the stope, and 4) depth of stope can be effectively used to estimate the probability of subsidence.
- A preliminary predictive tool has been developed that enables prediction of the probability of future subsidence potential in the Picher Mining Field.
- The magnitudes of possible subsidence at locations evaluated in this study range from less than 1 foot to greater than 50 feet, with the attendant possibility of loss of life and/or property, depending upon where the subsidence occurs.
- Land use determines the potential impact of a subsidence event on the population. For example, a one-foot subsidence in a road has more serious consequences than a similar or even larger subsidence in an agricultural area.

- Lowering of the groundwater table to levels below mine roof elevations may locally increase the probability of subsidence. This would probably only occur through pumping. However, water level fluctuations may cause increased shaft related collapses.
- A thorough evaluation of subsidence potential of a mined area must include a careful review of all available mine maps.
- It is likely that subsidence features exist in the study area that have not as yet been identified.
- No funding mechanism exists for emergency response to subsidence.

9 Recommendations and Options



The Eagle-Picher Mining & Smelting Company later developed a bigger version of the "Jumbo" (extending to 70 feet) to reach even higher to remove ore from the mine roof, pillars, and walls.

9. RECOMMENDATION AND OPTIONS

The following recommendations are intended to provide guidance to federal, state, and local officials in addressing the safety, environmental, and land use issues associated with potential subsidence events. The options provide a menu or a series of methods that can be applied to assist in the prediction, detection, and mitigation of subsidence. These recommendations are presented in two separate categories: general recommendations, and site-specific recommendations.

9.1 GENERAL RECOMMENDATIONS

General recommendations developed by the Subsidence Evaluation Team are:

- Establish an advisory committee composed of federal, state, and local representatives to assist with the implementation of recommendations contained in this report and to serve as a technical and/or management resource for policy makers and elected officials.
- Establish a long-term program to locate, map, and record future subsidence events as they occur in the Picher Mining Field. Both shaft related and non-shaft related subsidence events should be included in the program.
- Establish a fund to address emergency subsidence events in the Picher Mining Field. The fund should provide for emergency evaluation of subsidence features as they occur and provide an immediate funding source for corrective measures. Existing funding mechanisms do not provide the ability to respond quickly to emergencies. The fund would be replenished as it is drawn down.
- Continue the current mine-shaft closure program to remove the immediate hazards associated with open shafts, further reduce the potential for additional shaft failures, and minimize the environmental impacts from surface water drainage and unauthorized dumping. Focus mine-shaft closure efforts first on open mine shafts within city limits and near occupied structures.
- Develop and implement a subsidence training program for workers from Picher, Quapaw, Commerce, Ottawa County District 1, and Oklahoma Department of Transportation (ODOT) maintenance staff. The program should be designed to teach workers to recognize and report subsidence events and how to take appropriate action to address the subsidence events as they occur. A similar program has been in place in Joplin, MO for several years and has worked effectively.
- Identify and inspect all shaft related and non-shaft related subsidence features being used as dump sites for commercial and household refuse to reduce the environmental impacts of open subsidence features. A priority ranking based on the potential environmental impact should be developed and additional funding provided to eliminate surface runoff into the sites and, in some instances, close the sites not currently addressed. Governmental regulatory agencies, cities, and Ottawa County should work together to strengthen the regulations, enforcement, and penalties for unauthorized dumping and develop legal alternatives for trash disposal.
- Federal and State agencies involved in remediation and reclamation of lands at Tar Creek should reevaluate existing assumptions and approaches used to address hazards in the mining field. The information contained in this report (potential subsidence and mine shaft failure, underground mine workings) should be factored into existing projects, plans, and decisions. A process for evaluating current and future land use plans against existing hazards and the estimated cost for remediation and reclamation should be developed. A plan for restoration and/or final disposition of mined properties, including identification and mitigation of known hazards, should be a product of the effort. Ottawa County and impacted cities should establish a county-city land use planning process to evaluate current land use and develop future land use recommendations in the study area. Ottawa County should adopt building standards and land use guidelines for the mined lands.

- HUD regulations related to existing housing and future construction in the mining field should be reviewed to determine the applicability and impact.
- Identify a state agency responsible for maintaining and building upon the GIS developed from this project. The GIS information should be made available over the Internet or by some other electronic media.
- Complete subsidence evaluation for the remainder of the Picher Mining Field outside the study area and:
  - Further refine the subsidence evaluation model
  - Evaluate the effects of mine water on the stability of mine workings
  - Develop a better understanding of structural geology and physical and engineering properties of rock in the area
  - Incorporate additional mine maps and borehole data in the GIS
  - Evaluate failure mechanisms for recent smaller, non-shaft subsidence areas

9.2 SITE-SPECIFIC RECOMMENDATIONS

Given the results and conclusions of this study, site-specific measures are required to mitigate the potential impacts on public safety. A cost-benefit analysis should be performed to determine the most appropriate approach. Areas with higher probabilities and greater maximum estimated subsidence should be given priority with regard to evaluation and mitigation. The following site-specific measures are presented based on four categories of land use: public use areas, residential/commercial areas, major transportation corridors, and rural agricultural and undeveloped areas.

The no-action option is available for all undermined areas and may be the most appropriate for specific sites. This option will not be discussed any further in this report. Backfilling of mine workings is also an option for all categories; but due to extensive mine workings, the cost is prohibitive in all but very-high-value facilities. Specific situations where backfilling may be feasible are discussed below.

9.2.1 Public Use Facilities—Areas Where People Congregate Having a Maximum Estimated Subsidence of Five Feet or Greater

- Three options are available: close/relocate the facility, conduct a site-specific evaluation followed by either a geotechnical evaluation, or perform regular monitoring using visual or geotechnical methods. The costs of the evaluation, and possible long-term monitoring should be determined. The benefits of continuing to use these facilities should be evaluated against the risk and overall costs of closure/relocation, the geotechnical evaluation, and long term-monitoring.
- Locations in Picher where residents were previously evicted by the Eagle-Picher Mining & Smelting Company and public use was restricted by Eagle-Picher and BIA because of the potential for subsidence should be further evaluated prior to development of public use facilities or expansion of residential areas. The grade school playground (location 139), the youth soccer field (location 141), Reunion Park (location 140), Picher Little League Park (old baseball field in Picher on South Main between 5th and 6th Streets), between 1st and A Streets and north of D Street between Netta and Picher Streets, as described in Section 1.1.3, and other areas of high public use should be evaluated to determine if continued use is safe for residents.

9.2.2 Residential/Commercial Areas

- **Mineshafts in Residential, Commercial or Public Use Areas:** City and county workers should be trained to recognize the signs of potential mineshaft failure and periodically inspect all mineshafts located in the community. These areas should be zoned to restrict future residential, commercial, or public land use. The mine shafts should be investigated to determine if they are filled with durable material. If it is not, the shaft should be backfilled or plugged with concrete at the rock interface.

- **Mineshafts Beneath Structures:** If a structure is located immediately over a shaft, the structure should be relocated or demolished, or if cost effective, an angle drilling program should be conducted to determine if the shaft is completely backfilled. If drilling determines that the shaft is not completely backfilled or otherwise adequately plugged, the shaft should be backfilled or the structure should be relocated or demolished. After relocation or demolition of the structure, the shaft should be plugged at the rock interface or backfilled with nondegradable material. The cost of backfilling a shaft under a structure using angle drilling and grouting methods can be substantially greater than backfilling or plugging the same shaft without the structure. This entails drilling to determine the presence of mine voids and their depth and height, along with rock mechanics properties of the formation.

- **Maximum Subsidence Five Feet or Greater:** When a structure or structures overlies, or is within 150 feet of such an area, one of three options should be undertaken: perform exploratory drilling to determine the actual subsurface conditions, relocate the structure or structures, or demolish the structure or structures. Exploratory drilling may validate the original prediction, may show that the maximum estimated subsidence is either greater or less, and/or may reveal different information about the site such as the progression of mine roof collapse upward. If drilling shows that the site is not safe for continued occupation or use and mitigation isn't a sensible option, then relocation or demolition should be conducted. Any demolition must be followed by restrictions on future land uses. It is recommended that no new construction or relocation of residential housing, commercial buildings, infrastructure, or transportation systems be allowed immediately above or within 150 feet of undermined lands until the area is evaluated for potential subsidence.

- **Residential Areas of Quapaw:** Based on the small number of mine shafts identified in Quapaw, the mine workings are most likely not extensive or located near the surface. Competent limestone is found near the surface in other mines near Quapaw indicating a competent mine roof structure. The cost to perform a geotechnical evaluation to identify the extent of the mine workings, the height of the workings and the stability of the roof structure would be very expensive and disruptive to the community. Based on the absence of non-shaft related subsidence in the past, city workers should be trained to recognize and report any indications of subsidence or shaft failure.

9.2.3 Major Transportation Corridors

Even small collapses on transportation corridors have the potential to cause serious accidents. For all transportation corridors that have an estimated maximum subsidence of 0 to 2 feet, under or within 150 feet of the road, establish and implement a routine survey grade monitoring procedure, the results of which are reviewed by a qualified engineer on a prescribed schedule.

For all transportation corridors that have an estimated maximum subsidence of 2 feet or greater, under or within 150 feet of the road, or where a mine shaft is located under the road right of way, immediate recommendations are:

- Inform transportation and utility managers of potential risk
- Consider imposing weight restrictions and speed limits on vehicles
- Establish alternate routes for school buses

Long-term recommendations are:

- Establish a systematic, continuous monitoring and reporting program including, at a minimum, a survey grade network along effected areas
- Ensure that a qualified engineer or geologist reviews the monitoring data at regular intervals as a check on the quality control for the monitoring system.

- Conduct a geotechnical investigation to determine the stability of the roadbed surface and right-of-way
- A qualified engineer or geologist should review the results at regular intervals to ensure stability where a monitoring program is implemented
- Train city, county, and state transportation workers to recognize the signs of subsidence or shaft failure and to provide a reporting mechanism to expedite response to any suspected problem.
- Establish a standard protocol for all city, county, and state officials to use whenever they suspect that a shaft failure or subsidence may be occurring in or adjacent to a road. This should include notification procedures, road closure procedures, warning sign procedures, etc.
- Consider mitigation if cost effective

9.2.4 Residential Streets

Several residential streets in Picher, Cardin, and Hockerville have the potential for subsidence beneath or adjacent to the streets, (Table 7.2). Several streets in these towns have been built over mine workings; however, not all streets built over mine workings were identified as having a potential for subsidence. Federal, state, and local officials should assess the need for evaluating the streets having a potential for subsidence and other streets that overlie mine workings. For residential streets having an estimated maximum subsidence greater than 2 feet (Section 7.4.1), immediate recommendations are:

- Consider imposing weight restrictions and speed limits on vehicles
- Establish alternate routes for school buses

Long-term recommendations are:

- Establish a systematic, continuous monitoring and reporting program including, at a minimum, a survey grade network along effected areas
- Ensure that a qualified engineer or geologist reviews the monitoring data at regular intervals as a check on the quality control for the monitoring system.
- Conduct a geotechnical investigation to determine the stability of the roadbed surface and right-of-way
- A qualified engineer or geologist should review the results at regular intervals to ensure stability where a monitoring program is implemented
- Train city, county, and state transportation workers to recognize the signs of subsidence or shaft failure and to provide a reporting mechanism to expedite response to any suspected problem.
- Establish a standard protocol for all city, county, and state officials to use whenever they suspect that a shaft failure or subsidence may be occurring in or adjacent to a road. This should include notification procedures, road closure procedures, warning sign procedures, etc.
- Consider mitigation if cost effective

9.2.5 Rural, Agricultural and Undeveloped Areas

Areas used for pasture, hay, or row crops, and undeveloped areas used for hunting, off-road vehicle use, or hiking expose fewer people to dangers associated with subsidence than do roads or residential areas; yet, dangers to public safety and property still exist. Undeveloped and lightly developed portions of towns are likely locations for new construction or relocation of existing structures from other areas. It is recommended that no new construction or relocation of residential housing, commercial buildings, infrastructure, or transportation systems be allowed immediately above or within 150 feet of undermined lands until the area is evaluated for potential subsidence.

9.3 OPTIONS

Options are also provided for addressing subsidence hazards associated with existing mine workings. Table 9.1, presented and discussed in Section 9.8 of this report, is a generalized matrix for decision-makers to evaluate options presented in this report. The options are divided into the following four categories:

- Management approaches that may be used to address subsidence
- Instrumentation that could be installed for early detection of potential subsidence
- Mine geometry characterization to better understand the parameters contributing to potential subsidence
- Hazard mitigation options (hazard abatement) associated with subsidence

9.4 MANAGEMENT APPROACH OPTIONS

9.4.1 Observational Method

The Observational Method essentially permits the development and use of a simple model to represent a complex process with subsequent observations of the process results, updating and refinement of the model based on the observed performance, and continued use of the model to predict process performance and manage the problem at hand. The empirical methodology used for subsidence potential evaluation in this study is based on an analysis of actual mine subsidence events using data and information derived from archived mine maps and drill-hole data retrieved from pre-mining exploration logs. While the derived model is believed to be conservative (i.e., it is expected to over predict subsidence potential), its actual performance has not yet been confirmed. The observational method would therefore be focused on validating the empirical approach along with refining both the model and approach as indicated.

Physical observation, exploration and instrumentation would be the primary observational method tools that can be applied in the Picher Mining Field. Continuing expansion of the case-study data set and further proofing and analysis of the overall case-study data set may also be appropriate.

9.4.2 Adaptive Management

In general, adaptive management is an iterative, learning-oriented methodology for managing complex systems that are characterized by high levels of uncertainty. It is an iterative (cyclical) process of adapting management solutions to complex problems based on applying assumptions followed by observation and then re-applying new assumptions based on those observations to achieve a better management solution to the problem.

Adaptive management is well suited to be used in conjunction with the observational method and implemented for the Picher Mining Field project for the following reasons:

- The Picher Mining Field area is part of a complex system.
- The Picher Mining Field area is constantly changing.
- Land uses may change and evolve. For example, undeveloped land may be developed by commercial or private parties. This would change the associated potential effect if underground workings were to potentially subside in the area.
- Immediate action is required because of potential severe consequences to people living in the area currently and in the near future.
- There is uncertainty in the data set used to evaluate the Picher Mining Field system. Although there is a large amount of historical data associated with the mining activities that have occurred, there is much information that has been lost or destroyed. In addition, the physical and

engineering properties of the soil and rock in the study area have not been characterized with respect to subsidence.

- The management system for the Picher Mining Field must be adaptable to new data, policies, land uses, and other factors.

9.5 INSTRUMENTATION OPTIONS

Instrumentation may be used to collect real-time data for early warning of potential subsidence.

9.5.1 Options for Detecting Migrating Voids

Subsurface void migration is routinely monitored using several techniques that can be adapted for continuous, remote monitoring with results immediately available via the Internet. The following are two of the options:

Time Domain Reflectometry (TDR): Either standard TDR, using a coaxial cable, or optical TDR, using a fiber optic cable, can be used to measure propagation of roof failure toward the land surface. In either case, the cable is grouted in a borehole drilled vertically from the surface into the mine void. The surface-based hardware automatically measures the length of intact cable indicating a change when the roof failure breaks off the lower end of the grouted cable.

Multiple Point Borehole Extensometers (MPBX): MPBX are installed in boreholes drilled vertically from the ground surface to monitor strata displacements at predetermined horizons. Anchor points can be established just above the existing mine roof and at up to five additional locations in the same borehole to progressively monitor displacements. Data can be automatically recorded and transmitted via the Internet to a multitude of authorized users. Displacements accurate to 1/100 of an inch can be measured.

9.5.2 Options for Subsidence Detection and Measurement

The objective of this instrumentation is to detect the early ground movements that precede subsidence. Several manual and automatic techniques are available. Two of them are:

Precise Leveling Surveys: Classic subsidence monitoring programs utilize land-based survey (i.e., precise leveling) techniques to precisely measure the magnitude of subsidence at predetermined locations throughout a project site.

LIDAR: LIDAR (Light Detection and Ranging)is an aerial survey method that provides an accurate means of collecting topographic information that is not affected by tree canopy. Approximately 60% of the area was flown (aerial LIDAR) during 2004, with the remainder completed in early 2005. Tripod-based LIDAR has also most recently been used at the subsidence site over the Skelton Mine at the southern end of Highway 69 as it traverses the study area.

9.6 OPTIONS FOR MINE GEOMETRY CHARACTERIZATION

Although there are mine maps of the workings for many mine sites, these maps may not always be complete or accurate. Some of the mine sites do not have any mapping information, and other maps have been found to have conflicting information; there is the potential that caving after the termination of mining may have impacted the mine workings geometry. Methods for better defining the extent of mine workings and their effect on the surface are described in the following subsections.

9.6.1 Geophysical Methods

Geophysical methods such as ground-penetrating radar, seismic reflection or refraction, micro-gravity variation, magnetic, resistivity, spectral analysis of seismic surface waves, and nuclear resonance, have all been tried for use in locating and characterizing mine voids. These techniques have often been proposed as less expensive alternatives to exploratory drilling for characterization of geological conditions in mining areas. While some of these methods have been useful for the extrapolation of data between exploratory drill holes, the state reclamation program has found that they do not provide consistent underground mine mapping at the depths encountered in the Tri-State District. These technologies may have important applications for the detection of eminent subsidence resulting from the migration of mine voids to shallow depths at the Tar Creek site.

9.6.2 Infrared Photography

Infrared spectrometry provides the capability of photographing images in the infrared light spectrum, thereby capturing the thermal gradient of the images being photographed. Discussions with the USGS in Denver, Colorado and the Jet Propulsion Laboratory (JPL) in Pasadena, California indicate that new technologies have been developed that provide greater capability for infrared imaging. It may be possible to use infrared imaging to identify open mine shafts that are concealed by brush and other debris and to identify undetected, abandoned mine workings near the ground surface. USGS staff indicate that a low-level flight (~12,000 feet) using infrared imaging provides sufficient resolution to identify openings such as mine shafts. USGS staff indicates that the best time for such flights is following a rain shower where there is a difference in the evaporation rate from ground surfaces. Infrared imaging utilized in conjunction with accurate mine maps may provide an addition tool to identify mine shafts as well as mine workings that have the potential for subsidence. The use of infrared technology to update current conditions in the Picher Mining Field should be given consideration.

9.6.3 Exploratory Drilling

Exploratory drilling can provide the most accurate picture of the geological setting and the physical structure of mine workings. Exploratory boreholes should be considered for making hole-to-hole or hole-to-surface seismic tomographic measurements in order to determine cavity shape and geologic boundaries. However drilling is very costly to characterize a large area. Typically, costs range from $7/foot for rotary drilling to $35/foot for core drilling. Drilling is also very time-consuming and invasive to the community. Drillholes would provide an accurate vertical lithologic log of the area of concern. Coupled with mine maps, existing drill logs, and GIS, drilling would be a very effective method for determining the size and condition of underground mine workings. Although expensive, drilling remains one of the most reliable methods for characterizing underground mines for subsidence prevention and abatement.

9.7 HAZARD MITIGATION OPTIONS

In 1983 and 1986, the U.S. Bureau of Mines, in cooperation with state geological surveys issued reports on stability problems and hazard evaluations in the Oklahoma, Missouri, and Kansas portions of the Tri-State District (Luza, 1986). Among other things, these reports identified five methods of hazard abatement for mine subsidence: backfilling, grading to gentle slopes, fencing, controlled collapse with explosives, and public education were all suggested. Around the nation, other methods have also been used for abating hazards associated with subsidence. These methods are discussed below.

9.7.1 Fencing Options

Fencing has been used in the Tri-State Mining Area for many years to keep people out of subsidence areas. Fencing is intended to deter public contact and exposure to the mine problem, not to fix or stabilize it. The 1983 Bureau of Mines study of problems in the Kansas portion of the Tri-State Mining Area suggests that, where mines are in urban areas or near roads, six-foot-high cyclone fencing be installed with barbed wire canted out at the top. A major problem with theft exists with fencing. Chain-link fencing, which has been installed in more remote areas, is often stolen within a few weeks of installation. The BIA is currently considering using a stronger type of fencing that is less prone to theft. Chain-link fencing used in public areas, such as downtown Picher, OK, survived for years without major damage or theft. Fences would allow authorized access. Warning signs would be used to deter unauthorized entry. Fences should be set back far enough from shafts so that they are not undercut by future caving of the shaft. Fences are visible today surrounding mine subsidence pits and mine shafts in the Tri-State Mining Area. Many of these are damaged or partially undercut by water or advanced subsidence or have weathered away. Fences may be the most cost-effective method of protecting the public from the dangers of subsidence pits in many situations, but they must be erected with a plan for long-term maintenance and monitoring. It must also be acknowledged that fences will not keep out determined explorers who wish to enter the subsidence pit area for mineral hunting, fishing, or other water-related activities. The costs of fencing are dependent on local prices and on economies of scale.

9.7.2 Backfilling Options

Backfilling generally consists of placing material within the underground cavity to fill the open space and reduce the cavity size. There are several different types of backfilling methods that are discussed below. It is important to note that all backfilling techniques are very expensive and are unlikely to prove practical in the study area. However, backfilling may be cost effective in certain situations within the study area.

- **Hydraulic Flushing** is the filling of mine voids with granular materials transported in a water-based slurry. Material placement is controlled by use of grout curtains or aggregate bulkheads constructed remotely from the surface through drill holes. When mines are open and unobstructed, this method can result in up to 100% of void fill, effectively eliminating the potential for subsidence. Complete fill is verified either by personnel working in the mine or by drilling confirmation holes from the surface after completion of work to determine if roof contact has been made. This method has been used in Wyoming and other states to backfill coal mines under entire subdivisions. However, the process requires large volumes of material and water.

- **Grouting** is the process of placing a mixture of cementitious material and fine aggregate as a fill material into the mine void. The grout is typically placed at a low volume rate. Many states and the Office of Surface Mining (OSM) use gravity grouting to stabilize coal mines that begin to subside under homes, other buildings, and roads. This is often a cost-effective method of ground stabilization where mine voids are not too tall (less than 8 feet) and the area to be stabilized is limited to structures or roads. However, it can be used in mine voids of nearly any size and configuration. The cost of grouting may become a problem for larger mine areas. Three types of grouting are discussed below:
  - **Gravity Grouting** consists of placing a mixture of cementing agent (generally Portland cement) and fine aggregate into the mine level by means of a borehole. The most commonly used combination for mine grouting in the Midwest is a mixture of sand, Portland cement, and Type-F fly ash. The gravity head is the driving force used to place the grout. This is used frequently for abatement of subsidence under roads and structures associated with abandoned coal mine sites in Kansas and Missouri, and would be effective in certain situations in the Tri-State District.
  - **Pressure Grouting** is the process of pumping the grout mix into the mine area and overburden at pressures ranging from one-half to one psi per foot of thickness of overburden. Packers are used to seal the borehole so that pressure can be exerted on the grout. This is used frequently for abatement of subsidence under roads and structures associated with abandoned coal mine sites and would be effective in certain situations in the Tri-State District. Pressure grouting enables the operator to force grout into fractured and rubble zones, providing enhanced protection from subsidence.
  - **Compaction Grouting** is the injection of a stiff (low slump) grout at high pressure, up to 500 psi. The grout forms a ball at the point of injection and compacts the surrounding material. This method is used to stiffen foundation soils that have lost strength and bulk due to subsidence. It is also used to compact unstable fill in old mine shafts that were filled with trash or poorly backfilled in the past. It is cost-effective for poorly filled mine shafts and structure-size stabilization projects but is not suited for area-wide projects.

- **Grout Bags** are heavy fabric bags that are filled with grout and designed to be placed through a borehole and into the mine workings to build artificial mine pillars. As the bags fill, they form a column in the mine void to add additional support to the mine roof, reducing the potential for subsidence. They have been used successfully in Pennsylvania where abandoned coal mine roof heights can reach 16 feet.

  Staff from Hayward Baker, Inc. speculated that grout bags may be effective in mine rooms up to 30 feet tall (Kansas Department of Transportation [KDOT] Abandoned Mines Workshop, April

27, 2000). It is understood that grout bags were being considered for use in 2000 by KDOT for stabilization of a road along the state line between Picher, OK and Baxter Springs, KS. This method may also be used to construct underground barrier walls to contain pumped grout or hydraulic backfill materials.

9.7.3 Ground Surface Reinforcing Options

Ground surface reinforcement is typically applied to areas where relatively small, localized subsidence is anticipated and is not generally suited to areas where large (e.g., > 20 feet) subsidence features are anticipated.

Geotextile Materials such as high-strength webs and nets have been used to reduce the effects of ground failure under roads. KDOT has previously considered using this method to stabilize a road on the state line between Pitcher, OK and Baxter Springs, KS. The method has also been used to seal abandoned coal mine shafts beneath a landfill expansion in Colorado.

The method involves excavation of the soil material under the area to be protected to a depth several feet below final grade. The geotextile is unrolled and anchored along the edges, then backfill materials are placed over the material and compacted. It has been suggested, in some cases, that the ground be excavated to a solid geologic formation and the geotextile deep-anchored to increase stability.

Dynamic Compaction is a process for compacting soils at depth. The process involves dropping a weight in excess of 10 tons on a grid pattern from a given height. This method is sometimes used for highway work and may have application for stabilizing abandoned exploratory holes dug by early miners. The method has the potential to induce subsidence in areas where mine-roof structure has deteriorated substantially, so thorough knowledge of geologic conditions is important when planning its implementation. The Missouri Department of Transportation is currently considering the use of dynamic compaction for the Range Line Road project at Joplin, Missouri.

Caissons, Grade Beams, Soil Nails, Driven Piers, and Rock Anchors are all methods that may be used to stabilize structures built over subsidence-prone areas. They may reduce the danger of building damage and the cost of repairs after minor subsidence events occur. However, these do little to stabilize the ground and do not stop or slow the progress of subsidence events.

9.7.4 Relocation Option

Relocation has been used in a few situations across the country where no other alternative existed to protect the public from extremely dangerous situations. Relocation does not alleviate the problem, but it does remove the people from direct, daily access to it.

Relocation or buy-out in the study area could be used where the subsidence probability is high and where a cost-benefit analysis shows it to be the most cost-effective approach to protecting the residents. Relocation or buy-out could occur within or outside the study area and would likely be voluntary unless a government agency condemns the property.

Voluntary relocation or buy-out has several inherent problems. It can have a net result of dividing a community. It can also result in “off-limits” areas in communities where no development or activity can occur. This tends to bring down nearby property values and reduce the tax base of the area. For a variety of reasons, property values in the study area are significantly depressed, and the tax base has declined as a result of most businesses moving to other areas.

In 2002, the federal relocation costs for the Tar Creek Site were estimated to be between $49,000 and $118,000 per home. A voluntary buy-out initiated by Oklahoma Governor Brad Henry in the spring of 2005 resulted in 60 families with children under six years of age being bought out in Picher, Cardin and Hockerville at an average cost of $51,000 per family. This resulted in over 90% of the eligible families participating in the buy-out. As a result of the buy out, the 2005 school enrollment for Picher-Cardin schools is down 25%.

It is recognized that in many instances, public participation is often not complete or enthusiastic. All relocation/buy-out options have pros and cons. Multiple public surveys taken in the Picher-Cardin area since 2001 have shown that in excess of 85% of the residents favor a buy-out. While many homeowners may voluntarily participate in a buy-out, there may be a few who refuse to leave, increasing the risk of making the process very long and more expensive. Managing a relocation/buy-out program can be difficult because of situations where the majority of residents who favor a buy-out do not want to be penalized by the minority who choose to remain.

9.7.5 Institutional Control Options

Zoning – Zoning laws may be very effective at reducing new public exposure to subsidence-prone areas. With reliable mapping of subsidence-prone areas, zoning can be used to designate areas suitable for new developments of various types. Zoning based on subsidence potential maps can designate areas with the highest subsidence potential as off-limits areas, lower subsidence potential areas for open space uses, and still lower areas for parking lots or commercial developments where structural considerations make development a low-risk issue. Areas with the lowest potential for subsidence may be zoned residential and retail. Zoning will not eliminate the possibility of subsidence, but it can reduce the public and private costs when subsidence does occur.

Special Building Codes – The safety and structural integrity of buildings constructed over subsidence-prone areas may be significantly improved by using certain construction practices. Counties and local governments can implement building codes that require these practices for new construction in subsidence-prone areas. Special building codes are similar to zoning in that they do not eliminate the possibility of subsidence. However, special building codes differ from zoning in that they allow for more construction and development in higher-potential subsidence areas.

9.8 SCREENING OF OPTIONS TO ADDRESS SUBSIDENCE

Table 9.1 presents a generalized matrix for decision makers to evaluate options presented in this report. The table presents the implementability/constructability, effectiveness, time frames and initial and long term costs of the options. The options presented in this report are categorized into three types in Table 9.1. Investigative options are those methods that assess the condition of the mine workings and/or the ground surface through non-intrusive or intrusive means, i.e. geophysics, drilling or infrared photography, but only yield information at a particular point in time and do not provide constant monitoring of mine conditions. Predictive options are those that require a continuous monitoring of the ground surface or mine workings to provide an early warning of possible changing conditions which may lead to a subsidence event. Mitigative options are those options that provide stabilization of areas, prevent access (fencing), prevent placement of infrastructure (zoning), or prevent placement of structures not properly designed or reinforced to withstand subsidence (building codes) in areas that are predicted to have future subsidence. Previous sections provide detailed descriptions of the options presented in Table 9.1.

9.9 SECTION 9 REFERENCES

Luza, K. V., 1986, Stability Problems Associated With Abandoned Underground Mines in the Picher Mining Field, Northeast Oklahoma, Oklahoma Geological Survey, Circular 88, 114 p.

TABLE 9.1
OPTIONS TO ADDRESS SUBSIDENCE IN THE STUDY AREA

OPTION CATEGORY	OPTION	HAZARD MITIGATION (YES/NO)	IMPLEMENTABLE/ CONSTRUCTABLE	EFFECTIVENESS (NONE / LOW / MEDIUM / HIGH)	TIMEFRAME TO IMPLEMENT	INITIAL COST (CAPITAL)	LONG TERM COSTS (O&M)	COMMENTS
INVESTIGATIVE	GEOPHYSICAL METHODS	No	Yes	None	Variable	M	NA	Seismic reflection, resistivity, ground penetrating radar, etc. Overall usefulness in study area has not been evaluated
	EXPLORATORY DRILLING -CORE	No	Yes	None	Variable	L-M	NA	Used for characterization of material over lying mine workings, approximate cost $35/ft Estimated cost per 200 ft. borehole is $7,000. Overall costs dependent on number of holes required for evaluation.
	EXPLORATORY DRILLING - ROTARY	No	Yes	None	Variable	L-M	NA	Used for identifying mine working locations, cost approximately $7/ft Estimated cost per 200 ft. borehole is $1,400. Overall costs dependent on number of holes required for evaluation.
	INFRARED PHOTOGRAPHY	No	Yes	None	3-9 MO.	L	NA	Minimal application in study area as a result of recent detailed field surveys.
	Sonar	No	Yes	None	<1 MO	L	NA	Used to identify extent and geometry of mine workings. Requires multiple borings to better determine mine geometry.
PREDICTIVE	OBSERVATIONAL METHOD	No	Yes	Low	Continuous	NA	NA	Formal process of observing the study area. Observed indications of subsidence would be evaluated. Instrumentation may also be included in the observational method. May be applicable to limited areas such as city streets maintained by trained workers and Quapaw where no non-shaft related collapses have been identified. May require minimal training costs.
	ADAPTIVE MANAGEMENT	No	Yes	Low	Continuous	NA	NA	An iterative, learning oriented methodology to manage complex issues at Tar Creek.
	TIME DOMAIN REFLECTOMETRY (TDR)	No	Yes	Medium	3-12 MO.	H	H	Uses a fiber optic cable to measure propagating roof collapse. Could be used to monitor areas where the potential for subsidence exists. Although this technology has been effectively used in other mining (coal mining) areas as a warning system, it would need to be tested for applicability to the geologic setting in the study area. Cost range assumes TDR installation and monitoring at all locations where structures exist and areas have been identified as having potential for surface expression. Cost range also assumes maintenance and monitoring of system for 50 years.

TABLE 9.1 (Continued)
OPTIONS TO ADDRESS SUBSIDENCE IN THE STUDY AREA

OPTION CATEGORY	OPTION	HAZARD MITIGATION (YES/NO)	IMPLEMENTABLE/ CONSTRUCTABLE	EFFECTIVENESS (NONE / LOW / MEDIUM / HIGH)	TIMEFRAME TO IMPLEMENT	INITIAL COST (CAPITAL)	LONG TERM COSTS (O&M)	COMMENTS
PREDICTIVE (Continued)	MULTIPLE POINT BOREHOLE EXTENSOMETERS (MPBX)	No	Yes	Medium	3-12 MO.	H	H	Monitoring devices are installed in vertical boreholes to monitor strata displacement. Could be used to monitor areas where the potential for subsidence exists. Cost range assumes MPBX installation and monitoring at all locations where structures exist and areas have been identified as having potential for surface expression. Cost range also assumes maintenance and monitoring of system for 50 years.
	PRECISE LEVELING SURVEYS	No	Yes	Low	1 MO.	L	H	Not considered to mitigate hazard because method identifies surface expression as it occurs, rather than providing advance warning. Long term monitoring cost range assumes length of time of 50 years.
	LIGHT DETECTION AND RANGING (LIDAR)	No	Yes	Low	6 MO.	M	L	Although not used as part of the subsidence evaluation LIDAR is a promising technology
MITIGATIVE	FENCING	Yes	Yes	Medium*	2 MO.	L	L	Fencing mitigates hazard only in areas where actual subsidence area does not affect structures or roads, primarily agricultural. Fencing must be maintained and monitored to ensure that it is not affected by theft or unauthorized cutting/entry. (* only medium effectiveness if security and monitoring of fence as indicated above is performed)
	WARNING SIGNS	Yes	Yes - Simple	Low	2 MO.	L	L	Prone to theft
	HYDRAULIC FLUSHING	Yes	Yes –Complex	High	Variable	H-VH	NA	Due to the size of the mine workings in the study area the cost would be significant.
	GRAVITY GROUTING	Yes	Yes – Complex	High	Variable	H-VH	NA	Due to the size of the mine workings in the study area the cost would be significant.
	PRESSURE GROUTING	Yes	Yes – Complex	High	Variable	H-VH	NA	Due to the size of the mine workings in the study area the cost would be significant.
	COMPACTION GROUTING	Yes	Yes – Complex	High	Variable	H-VH	NA	Not suited for area wide projects.
	GROUT BAGS	Yes	Yes – Complex	High	Variable	H	NA	Application for mine workings not exceeding 30 ft. in height.
	REINFORCING WITH GEOTEXTILE MATERIALS	Yes	Yes - Complex	Low – Areas of large subsidence Medium – Areas of small subsidence	6 MO.	M-H	NA	Has not been used at the Tar Creek site. The application has not been evaluated for the study area. Site specific evaluation would need to be conducted prior to implementation.
	DYNAMIC COMPACTION	Yes	Yes	Low	6 MO.	L-M	NA	A process of compacting soil to depths. May have limited application in the area for stabilizing exploratory holes dug by early miners.

TABLE 9.1 (Continued)
OPTIONS TO ADDRESS SUBSIDENCE IN THE STUDY AREA

OPTION CATEGORY	OPTION	HAZARD MITIGATION (YES/NO)	IMPLEMENTABLE/ CONSTRUCTABLE	EFFECTIVENESS (NONE / LOW / MEDIUM / HIGH)	TIMEFRAME TO IMPLEMENT	INITIAL COST (CAPITAL)	LONG TERM COSTS (O&M)	COMMENTS
MITIGATIVE (Continued)	CAISSONS, GRADE BEAMS, SOIL NAILS, DRIVEN PIERS, ROCK ANCHORS	No	No	Low	NA	NA	NA	Does little to stabilize the ground or stop or slow the progress of subsidence events
	RELOCATION	Yes	Yes	High	6-14 MO.	H	NA	May be coupled with demolition of structures to prevent future habitation and fencing
	ZONING	Yes	Yes	Medium	6 MO.	L	L	Mitigates hazard for future construction only, by avoiding areas of potential subsidence through zoning. Building codes are currently not in place. Does not mitigate hazards to existing structures located in identified areas of potential surface expression. Requires enforcement
	SPECIAL BUILDING CODES	Yes	Yes	Medium	6 MO.	L	L	Mitigates hazard for future construction only, by avoiding areas of potential subsidence through zoning. Building codes are currently not in place. Does not mitigate hazards to existing structures located in identified areas of potential surface expression. Requires enforcement

Notes:

Costs	Low	$200,000
	Medium	200,000-$2 Million
	High	$2-50 million
	Very High	$50million

NA – Not applicable
Implementable/Constructable – the degree to which an option presented is able to be put into effect or is able to be constructed according to a definite plan or procedure
Effectiveness – the degree to which the options presented are able to achieve stated goals as judged in terms of both output and impact

10 Glossary

Damage was extensive to the homes involved in the mine 1967 subsidence in Picher.

10. GLOSSARY

alluvium	A general term for clay, silt, sand, gravel or similar unconsolidated detrital material deposited during comparatively recent geologic time in a stream or other body of rushing water.
analysis of covariance	A statistical measure of the variance of two random variables measured in the same mean time period; equal to the product of the deviations of corresponding values of the two variables from their respective means.
analysis of variance	An analysis of the variation in the outcomes of an experiment to assess the contribution of each variable to the variation.
ArcGIS	A Geographic Information System computer software.
assaying	To analyzing the proportions of metals in an ore.
back-analysis	A method developed to look at existing subsidence features and analyze the drill logs and mine maps to determine common traits in the group of failures. The logs and maps from the failures are compared to several maps and logs of mines that did not subside to identify the greatest risk factors for subsidence.
Boone	The name of the uppermost aquifer in the Tri-State mining region. Mining occurred within this geologic formation.
borehole	A circular hole made by boring, especially a deep vertical hole of small diameter, such as a shaft, a well, or a hole made to ascertain the nature of the underlying formations.
boulder ground	Miners' descriptive term for a geologic formation encountered during mining activities.
buffer	A pre-determined zone around the actual zone of interest that adds a greater amount of protection to determinations made about risks in the mining area.
bulking factor	The increase in volume of a material due to manipulation. Rock bulks upon being excavated; damp sand bulks if loosely deposited, such as by dumping, because the apparent cohesion prevents movement of the soil particles to form a reduced volume. (ASCE). Or: The difference in volume of a given mass of sand or other fine material in moist and dry conditions; it is expressed as a percentage of the volume in a dry condition.
chat	Name for finely crushed gangue remaining after the extraction of lead and zinc minerals in the Tri-State District of Missouri, Kansas, and Oklahoma. The term is derived from chert.
chert	A sedimentary form of amorphous or extremely fine-grained silica, partially hydrous, found in concretions and beds.
Chester	Refers to the Chester series of rock formations within the uppermost Mississippian period.
Chester shale	A shale formation within the Chester series of rocks.

collar elevation	The ground surface elevation of the timbering or concrete lining around the top of a shaft.
competent bed	Said of a bed or stratum that is able to withstand the pressures of folding without flowage or change in original thickness. Or: Said of a fold in which the strata have not flowed or changed their original thickness.
crop out	Verb form of outcrop: a rock formation appearing at the ground surface.
dichotomous	Divided into two parts for classification.
DEM	Digital Elevation Model. A digital set of x, y and z data.
digitized	Put into digital form, as for use in a computer.
disconformable	An unconformity in which the bedding planes above and below the break are essentially parallel, indicating a significant interruption in the orderly sequence of sedimentary rocks.
drill log	A record, filled out on a tabulated form by the chief of the crew that dills an exploratory hole, showing drill progress and rock formations in sequence.
easting	The difference in longitude between two points as a result of movement to the East.
floatation fines	The waste material from a floatation process.
fossiliferous	Contains fossils, the remains, trace or imprint of a plant or animal that has been preserved by natural processes in the Earth's crust (rocks) since some past geologic time.
friable	Said of a rock or mineral that crumbles naturally or is easily broken, pulverized or reduced to powder such as a soft or poorly cemented sandstone.
froth flotation	The method of mineral separation in which a froth created in water by a variety of reagents floats some finely crushed minerals whereas other minerals sink.
galena	A mineral, lead sulfide, PbS. Principal ore of lead.
georeferenced	The process of linking a file or an image to a map using Global Positioning System (GPS) coordinates.
geotechnical evaluation	Drilling and data gathering carried out to determine soil and rock characteristics. Used to determine if unfavorable rock or soil conditions are present under proposed building sites.
graben	A block, generally long compared to its width, that has been downthrown along faults relative to the rocks on either side.
hazard	Danger; risk or peril; something causing danger or peril.
hertz (Hz)	The SI unit of frequency. One hertz is defined as one cycle per second. The unit may be applied to any periodic event – for example, a clock might be said to tick at 1 Hz.

hogchow	Miners' descriptive term for a chalky, porous chert; tripoli.
InSAR	A technique to measure and map changes on the Earth's surface as small as a few millimeters by bouncing radar signals off the ground surface from the same point in space but at different times.
interferograms	Maps of relative ground surface change constructed from InSAR data.
interpolation	The process of estimating a value of a function or series between two known values.
jack	A name for zinc ore; blackjack.
karst	A type of topography that is formed on limestone, gypsum, and other rocks by dissolution and that is characterized by sinkholes, caves, and underground drainage.
LIDAR	An aerial survey to map the topography of the ground surface elevation.
limestone	A sedimentary rock consisting chiefly of calcium carbonate.
load	The act or process of placing an explosive in a borehole; also, the explosive so placed. Or: Of a stream, the amount that it carries at any one time.
logistic regression	A form of regression that is used when the dependent (or response) variable is a dichotomous (or binary) and the independent (or explanatory) variables are continuous, dichotomous, or categorical.
marcasite	White iron pyrites, FeS_2, the orthorhombic dimorph of pyrite, having a lower specific gravity, less stability, and a paler color. Often called white iron pyrites, coxcomb pyrites, and spear pyrites.
metadata	An explanation of where and how the data was gathered and stored.
multivariate	Involving more than one variable.
mundic	A drillers' term for pyrite.
natural neighbors	A weighted moving average interpolation technique that uses geometric relationships in order to create a continuos surface from data points.
nodular chert	Chert in the form of nodules; small sedimentary hard and irregular rounded or tuberous body (knot, mass, lump) of a mineral or mineral aggregate, normally having a warty or knobby surface and no internal structure, and usually exhibiting a contrasting composition from and a greater hardness than the enclosing sediment or rock matrix in which it is embedded.
ore	The naturally occurring material from which a mineral or minerals of economic value can be extracted.
northing	The difference in latitude between two positions as a result of movement to the North.
ore horizon	The zone in which an ore body resides.

overburden Material of any nature, consolidated or unconsolidated, that overlies a deposit of useful materials, ores, or coal, especially those deposits that are mined from the surface by open cuts. Or: Loose soil, sand, gravel, etc., that lies above the bedrock. Also called burden, capping, cover, drift, mantle, surface.

oxygenated To treat, combine, or enrich with oxygen.

probability The likelihood of occurrence; often expressed as a ratio of the number of actual occurrences to that of possible occurrences.

raise A vertical or inclined opening within a mine, driven upward to connect two levels.

raster A data file or structure representing a generally rectangular grid of pixels, or points of color, on a computer monitor, paper, or other display device

regression A mathematical method of determining the empirical relationship between a dependent and one or more independent variables.

risk Exposure to the chance of injury or loss.

rise A vertical or inclined shaft from a lower to an upper level in a mine.

rockfall The relatively free falling or rapid movement of a newly detached segment of bedrock (usually massive, homogeneous, or jointed) of any size from a cliff or other very steep slope; it is the fastest form of mass movement and is most frequent in mountain areas and during spring when there is repeated freezing and thawing of water in cracks in the rock. Movement may be straight down, or in a series of leaps and bounds down the slope; it is not guided by an underlying slip surface. Similar rock falls occurred underground in mines, caused by faults or weaknesses in the rock structure, or faults created during blasting.

room and pillar method Said of a system of mining in which typically flat-lying beds of coal or ore are mined in rooms separated by pillars of undisturbed rock left for roof support. Or: In coal and metal mining, a method that supports the roof by pillars left at regular intervals.

Roubidoux The geologic formation of Ordovician age and the deep aquifer in which much of the drinking water supplies for much of Ottawa County occur.

sandstone A medium grained clastic sedimentary rock composed of abundant and rounded or angular fragments of sand size set in a fine grained matrix and more or less firmly united by a cementing material.

shaft An excavation of limited area compared with its depth; made for finding or mining ore or coal, raising water, ore, rock, or coal, hoisting and lowering workers and material, or ventilating underground workings. The term is often specifically applied to an approximately vertical shaft, as distinguished from an incline or inclined shaft. A shaft is provided with a hoisting engine at the top for handling workers, rock, and supplies; or it may be used only in connection with pumping or ventilating operations.

shale A fine grained detrital sedimentary rock formed by the consolidation of clay, silt, or mud and characterized by a finely stratified structure.

shines	Generally reefers to trace minerals such as zinc in drilling logs. Analyses of that segment of the drilling core that reveals whether enough metal was present to mine a particular area.
sinkhole	Depression in the surface of the ground caused by collapse subsidence of roof over solution cavern. General term sometimes given to mine roof failure.
spectral acceleration	Approximately the acceleration that is experienced by a building during a period of peak ground acceleration (during an earthquake), as modeled by a particle on a massless vertical rod having the same natural period of vibration as the building.
sphalerite	A mineral, zinc sulfide, ZnS. Nearly always contains iron. Principal ore of zinc.
statistical analysis	An analysis of, pertaining to, consisting of, or based on statistics (classification, analysis, interpretation of numerical facts).
stope	An excavation from which ore has been removed in a series of steps. A variation of step. Usually applied to highly inclined or vertical veins. Frequently used incorrectly as a synonym for room, which is a wide-working place in a flat mine. Or: To excavate ore in a vein by driving horizontally upon it a series of workings, one immediately over the other, or vice versa. Or: Commonly applied to the extraction of ore, but does not include the ore removed in sinking shafts and in driving levels, drifts, and other development openings.
stratigraphy	The study of rock strata. It is concerned not only with the original succession and age relations of rock strata but also with their form, distribution, lithologic composition, fossil content, geophysical and geochemical properties; indeed, with all characters and attributes of rocks as strata; and their interpretation in terms of environment or mode of origin, and geologic history. All classes of rocks, consolidated or unconsolidated, fall within the general scope of stratigraphy. Some nonstratiform rock bodies are considered because of their association with or close relation to rock strata.
subsidence	The lowering of the Earth's surface, caused by such factors as compaction, a decrease in groundwater, or the pumping of oil. Or: The sudden sinking or gradual downward settling of the Earth's surface with little or no horizontal motion. The movement is not restricted in rate, magnitude, or area involved. Subsidence may be caused by natural geologic processes, such as solution, thawing, compaction, slow crustal warping, or withdrawal of fluid lava from beneath a solid crust; or by human activity, such as subsurface mining or the pumping of oil or groundwater.
surface expression	A depression of the ground surface above an underground excavation caused by the failure and collapse of the excavation. An underground failure or collapse that is large enough to cause a depression up to the surface.
syncline	A folding of the geologic formations in which the core contains the stratigraphically younger rocks; it is concave upward.
tectonic origin	Originating from Earth's crustal movements resulting in structural or deformational features.
topography	Shape and physical features of land.

vector data structure	A coordinate-based data structure commonly used to represent map features. Each liner feature is represented as a list of ordered x, y coordinates. Attributes are associated with the feature (as opposed to a raster data structure, which associates attributes with a grid cell).
winze	A vertical or near-vertical opening sunk from a point inside a mine to connect with a lower level or to explore the ground to a limited depth below a level.

Acronyms

COE	U.S. Army Corps of Engineers
DEM	Digital Elevation Model
DEQ	Department of Environmental Quality
DTM	Digital Terrain Model
EPA	U.S. Environmental Protection Agency
ESRI	Environmental Systems Research Institute, Inc
GIS	Geographic Information System
GPS	Global Positioning System
InSAR	Interferometric Synthetic Aperture Radar
LIDAR	Laser Identification Detection and Ranging
OCC	Oklahoma Conservation Commission
OGS	Oklahoma Geological Survey
OSM	Office of Surface Mines
TIN	Triangulated Irregular Network
USGS	United States Geological Survey

APPENDIX A

PICHER MINING FIELD SUBSIDENCE EVALUATION MAP LIST

APPENDIX B
BOREHOLE DATA

APPENDIX C
CHRONOLOGY OF THE NETTA MINE SITE, PICHER, OKLAHOMA

APPENDIX D

SUBSIDENCE CASE STUDIES

APPENDIX E

MINE COLLAPSE LOGISTIC REGRESSION MODEL

APPENDIX F

ESTIMATED MAXIMUM SUBSIDENCE 150-FOOT BUFFER MAP